NASA-CR-58281) A CCMPARATIVE DESIGN STUDY OF MCDULAR STAGE CONCEPTS FOR LUNAR SUPPLY OPERATIONS. VOLUME 3: DEVELOPMENT FLANS AND COST (TRW Space Technology Labs., Redondo Beach) 148 p

N74-71639

Unclas 00/99 30039

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(NASA CR OR TMX OR AD NUMBER)

COMPARATIVE DESIGN STUDY OF

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MODULAR STAGE CONCEPTS FOR

# LUNAR SUPPLY OPERATIONS (U)

CLASSIFICATION CHANGE

10 - UNCLASSIFIED

(National and the Black)

By authority of T.D. No.

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VOLUME III - DEVELOPMENT PLANS AND COST ANALYSES

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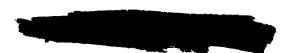
Prepared for

MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Huntsville, Alabama

TRW SPACE TECHNOLOGY LABORATORIES

THOMPSON RAMO WOOLDRIDGE INC.

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A COMPARATIVE DESIGN STUDY OF MODULAR STAGE CONCEPTS FOR LUNAR SUPPLY OPERATIONS (U)

Volume III - Development Plans and Cost Analyses

## Prepared for

MARSHALL SPACE FLIGHT CENTER NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Huntsville, Alabama

Under Contract No. NAS8-11022

"Available to U.S. Government Agencies and U. S. Government Contractors Only"

12 December 1963

# TRW SPACE TECHNOLOGY LABORATORIES

THOMPSON RAMO WOOLDRIDGE INC.

SPACE PARK . REDONDO BEACH, CALIFORNIA



## PREFACE

This report presents the final results of a comparative design study of lunar direct flight manned and logistic spacecraft performed for the Marshall Space Flight Center, NASA, by TRW Space Technology Laboratories under contract NAS8-11022. The study was performed during the period June 28 through November 28, 1963.

The purpose of the study was to assess from a performance and cost standpoint the relative merits of vehicle systems tailored to optimize performance compared to systems based on modular concepts. The study included consideration of system and subsystem design and development requirements and an analysis of development and operational cost.

Volume I of this report presents a summary of the principle results of the study. Volume II, issued in two parts, provides the details of the vehicle and ground system design and analysis. Volume III covers the development plans and cost analysis.

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#### 1. INTRODUCTION

## 1.1 OBJECTIVE

The object of this study is to define, compare, and evaluate direct lunar flight pairs of tailored spacecraft optimized for the missions under consideration with pairs of spacecraft performing a similar function but which utilize a modular concept in their design. The object of this particular report is to present the development programs as well as cost estimates and comparisons for these spacecraft pairs.

#### 1.2 DESCRIPTION

This report presents cost analyses for eight different direct flight vehicles. These vehicles have been combined into various pairs of manned and logistics configurations in order to determine those which have lower cost requirements when both development and recurring costs are considered. The effects of commonality between configurations as well as the effects of a learning curve on recurring costs have been included in the estimates.

In addition to the costs for each configuration, a separate estimate of development costs of a single module is included.

In order to prepare the cost analyses it was necessary to establish development programs for each of the configurations considered. Detailed development programs are presented for the tailored and modular pairs (four configurations). The program plans for the other configurations are not presented in this much detail; instead the summary information is presented.

## 2. SUMMARY

## 2.1 SPACECRAFT

Program plans and cost estimates have been prepared for eight lunar direct flight vehicles. These vehicles have been combined into various pairs of manned and logistics configurations in order to determine the costs of these combinations.

The vehicles are described in detail in Volume II of this report, however, they are shown here for reference purposes. The specific configurations are:

- a) Tailored Logistics Configuration SB 625 (PD60-19) (Figure 2-1)
- b) Tailored Manned Configuration SB 713 (PD60-30) (Figure 2-2)
- c) Modular Logistics Configuration SB 809 (PD60-67) (Figure 2-3)
- d) Modular Manned Configuration SB 910 (PD60-65) (Figure 2-4)
- e) Hybrid Logistics Configuration SB 810 (PD60-68) (Figure 2-5)
- f) Hybrid Manned Configuration SB 911 (PD60-71) (Figure 2-6)
- g) Single Stage Logistics Configuration SB 529 (PD60-16) (Figure 2-7)
- h) Hybrid B Manned Configuration SB 908 (PD60-44) (Figure 2-8)

## 2.2 DEVELOPMENT PLANS

The underlying idea in the multimission module (MMM) approach is that the use of a module common to several mission applications can lead to significant simplifications in the overall development effort,

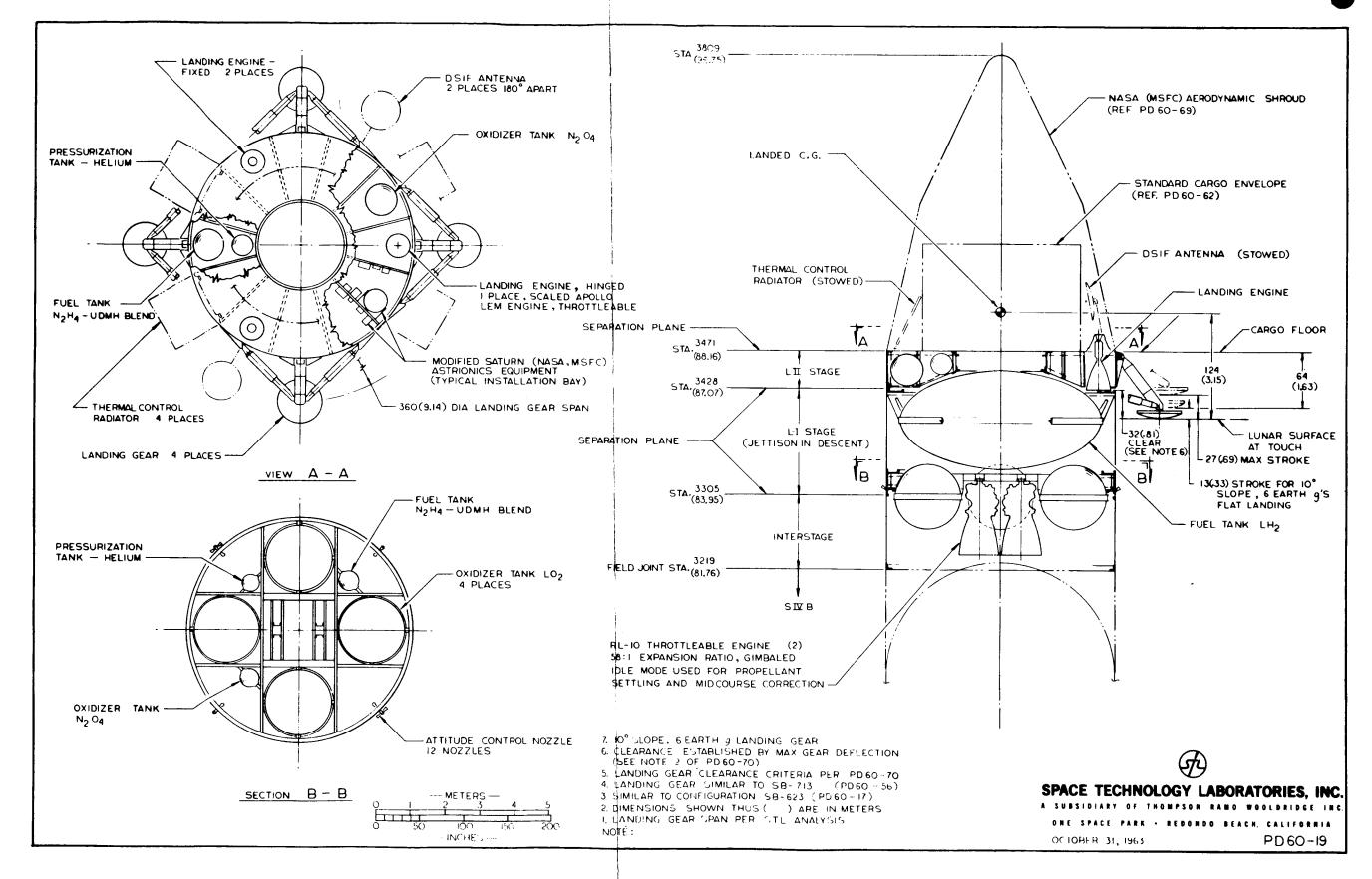


Figure 2-1. Tailored LLS, Two Stage - Configuration SB-625

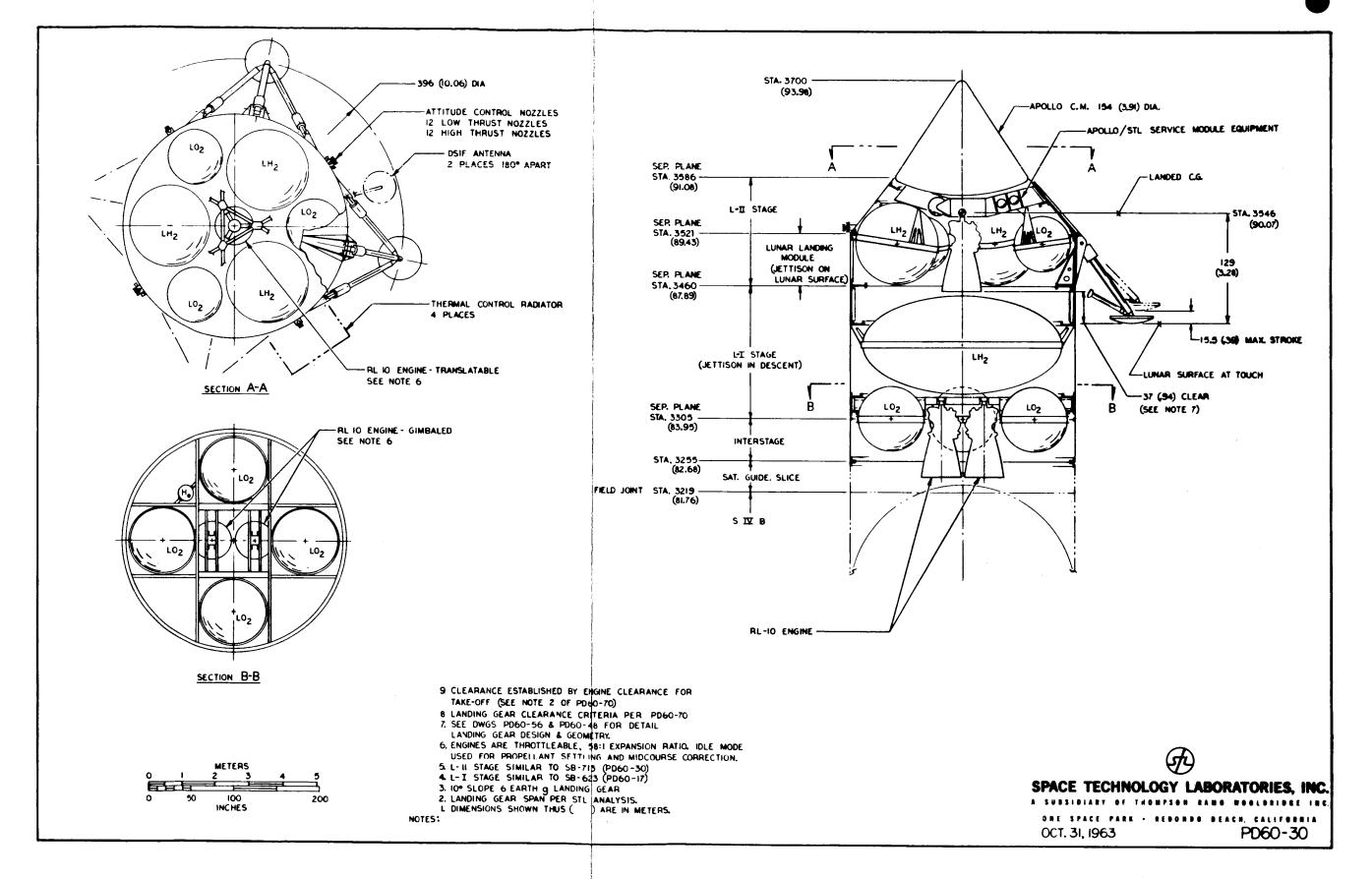


Figure 2-2. Tailored, Manned, Two Stage-Configuration SB-713

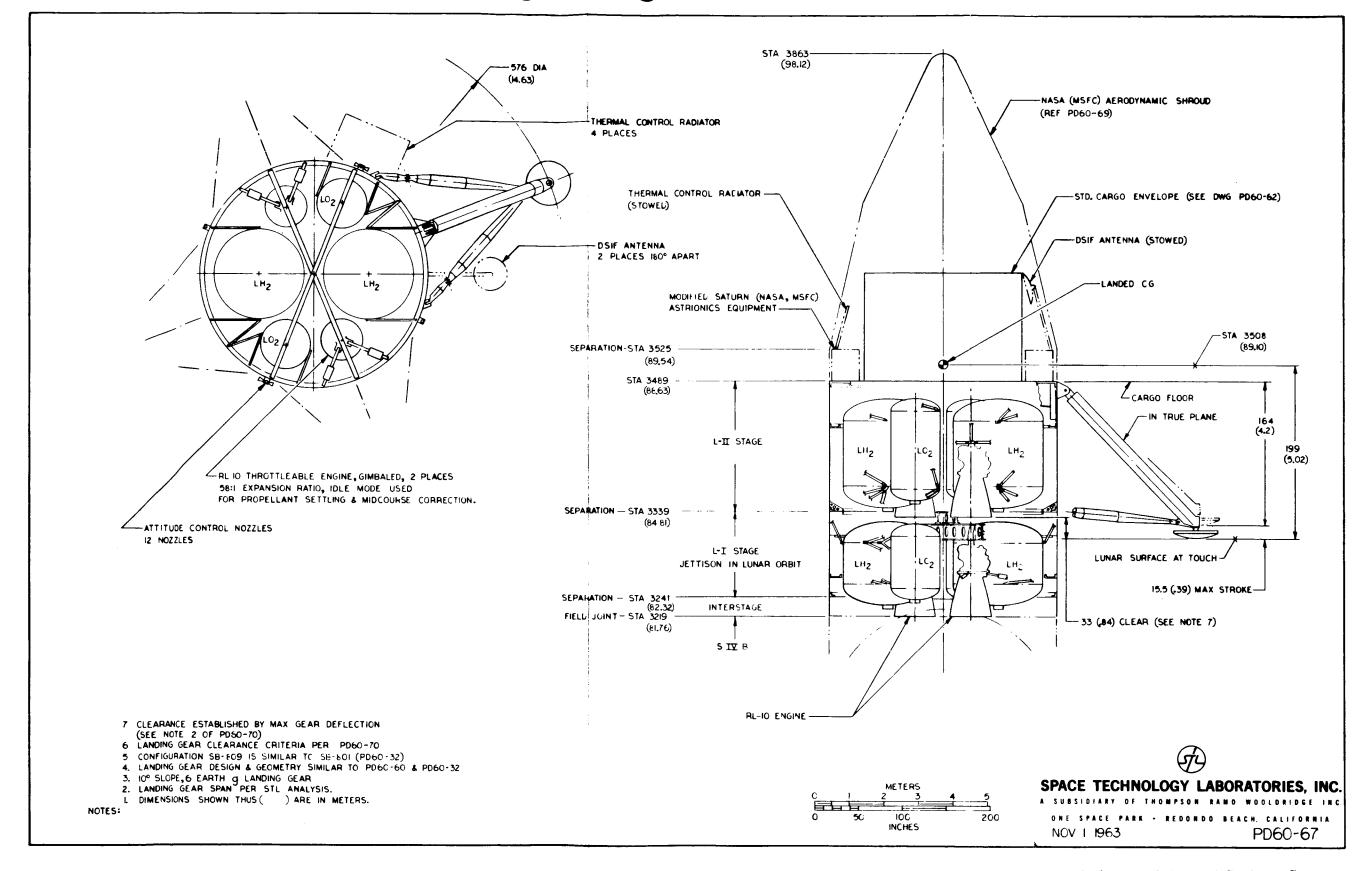


Figure 2-3. Modular LLS, Two Stage - Configuration SB-809

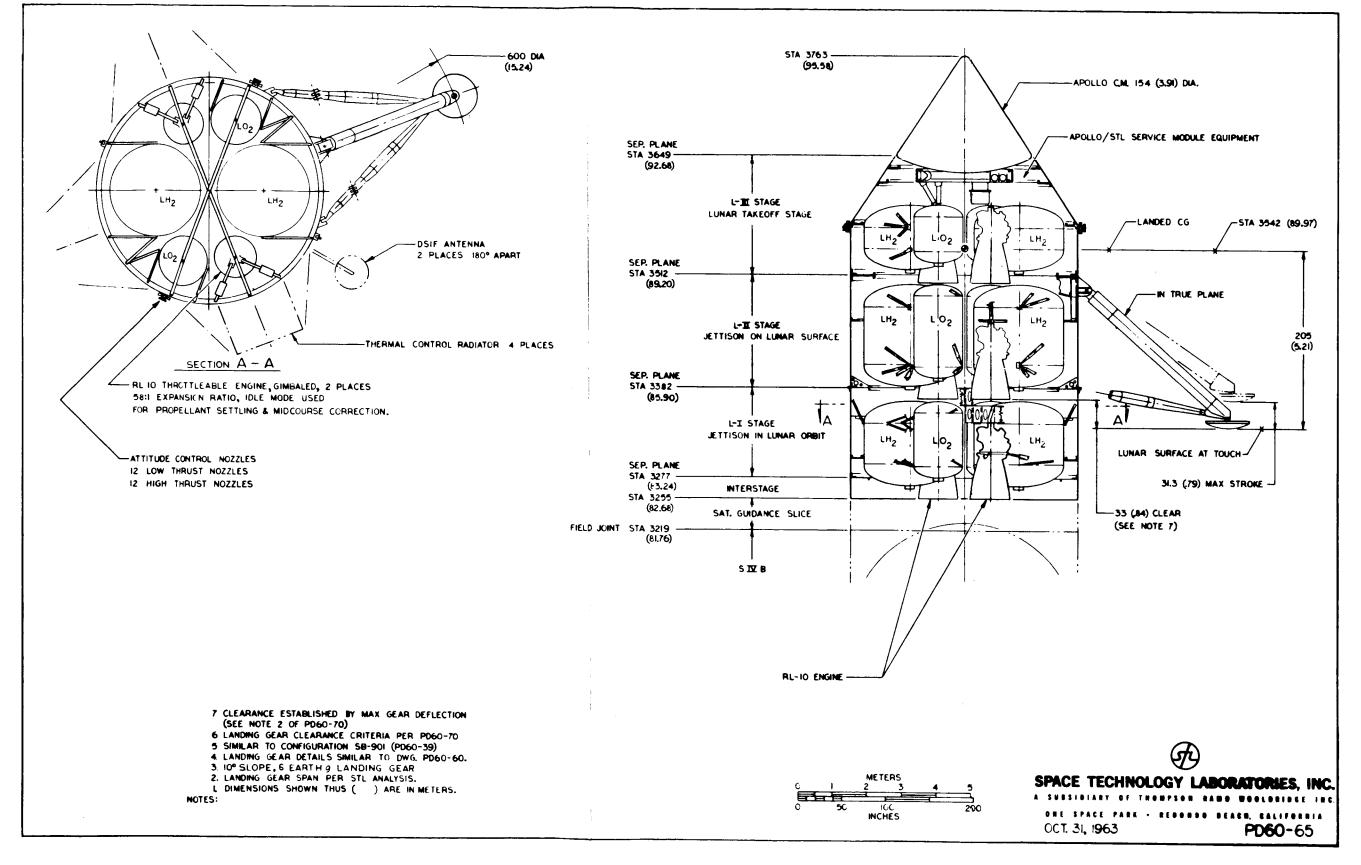


Figure 2-4. Modular, Manned, Three Stage-Configuration SB-910

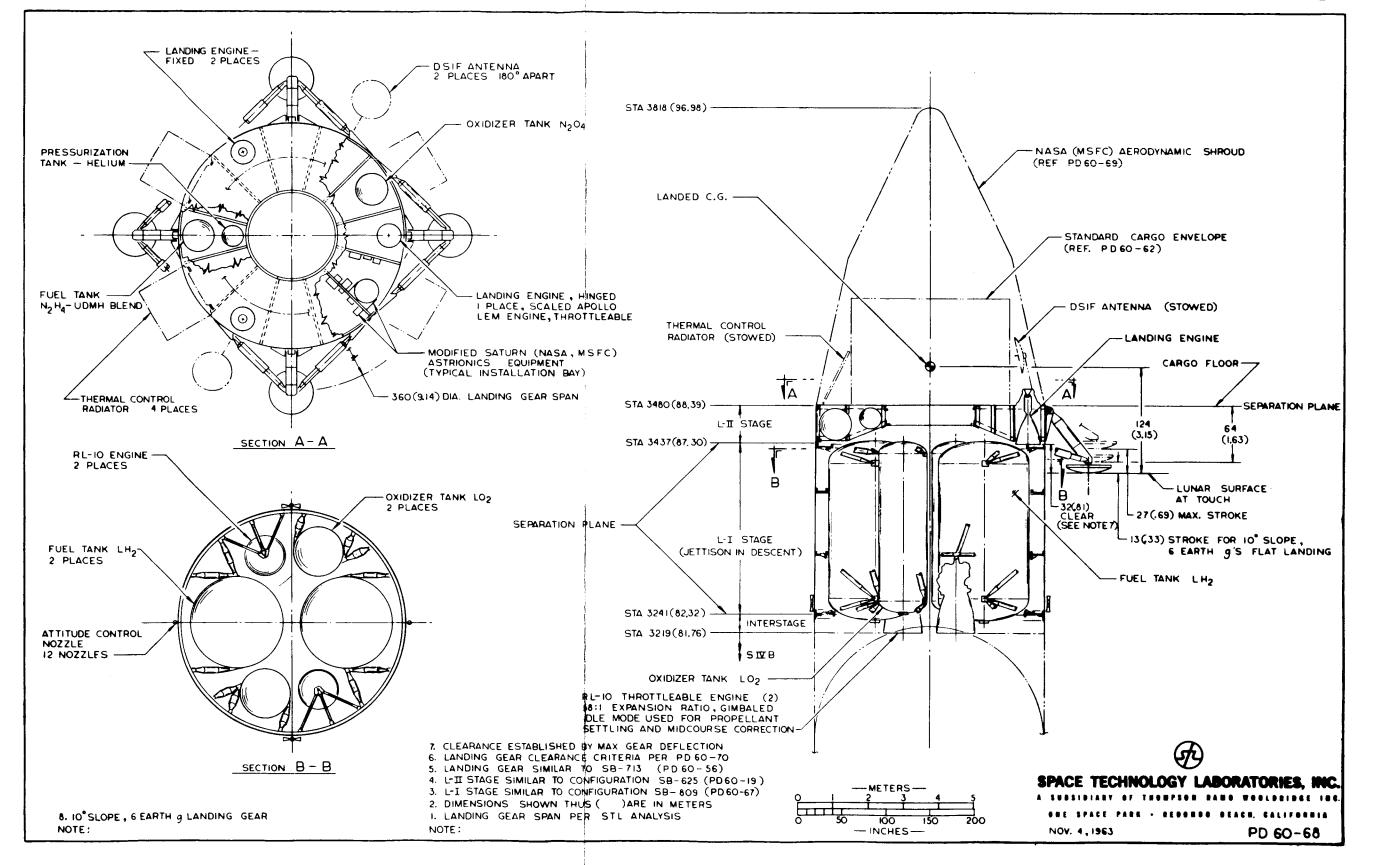


Figure 2-5. Hybrid, Two Stage, LLS (L-I Modular, L-II Tailored) - Configuration SB-810

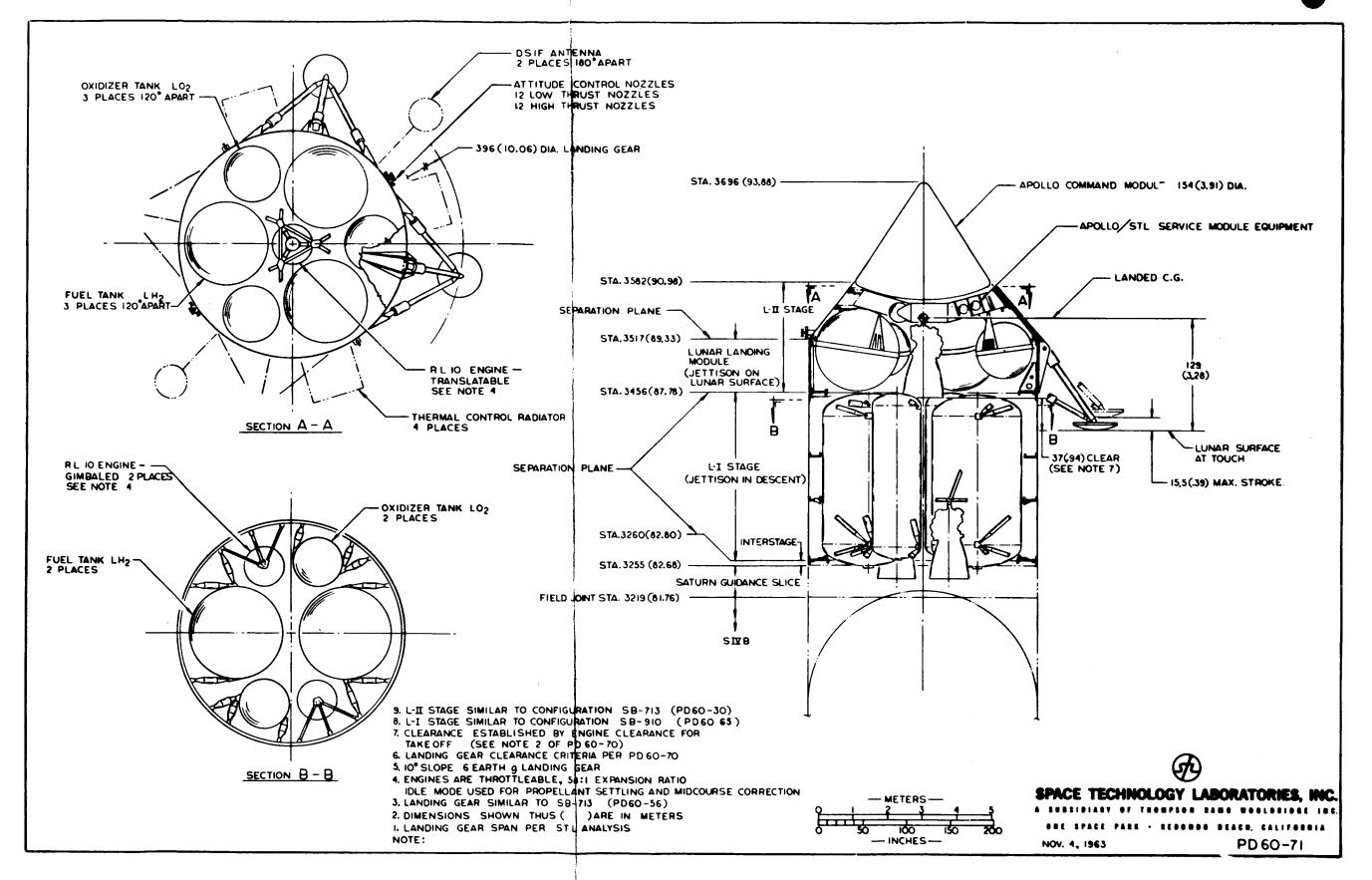


Figure 2-6. Hybrid, Two Stage, Manned (L-I Modular, L-II Tailored) - Configuration SB-911

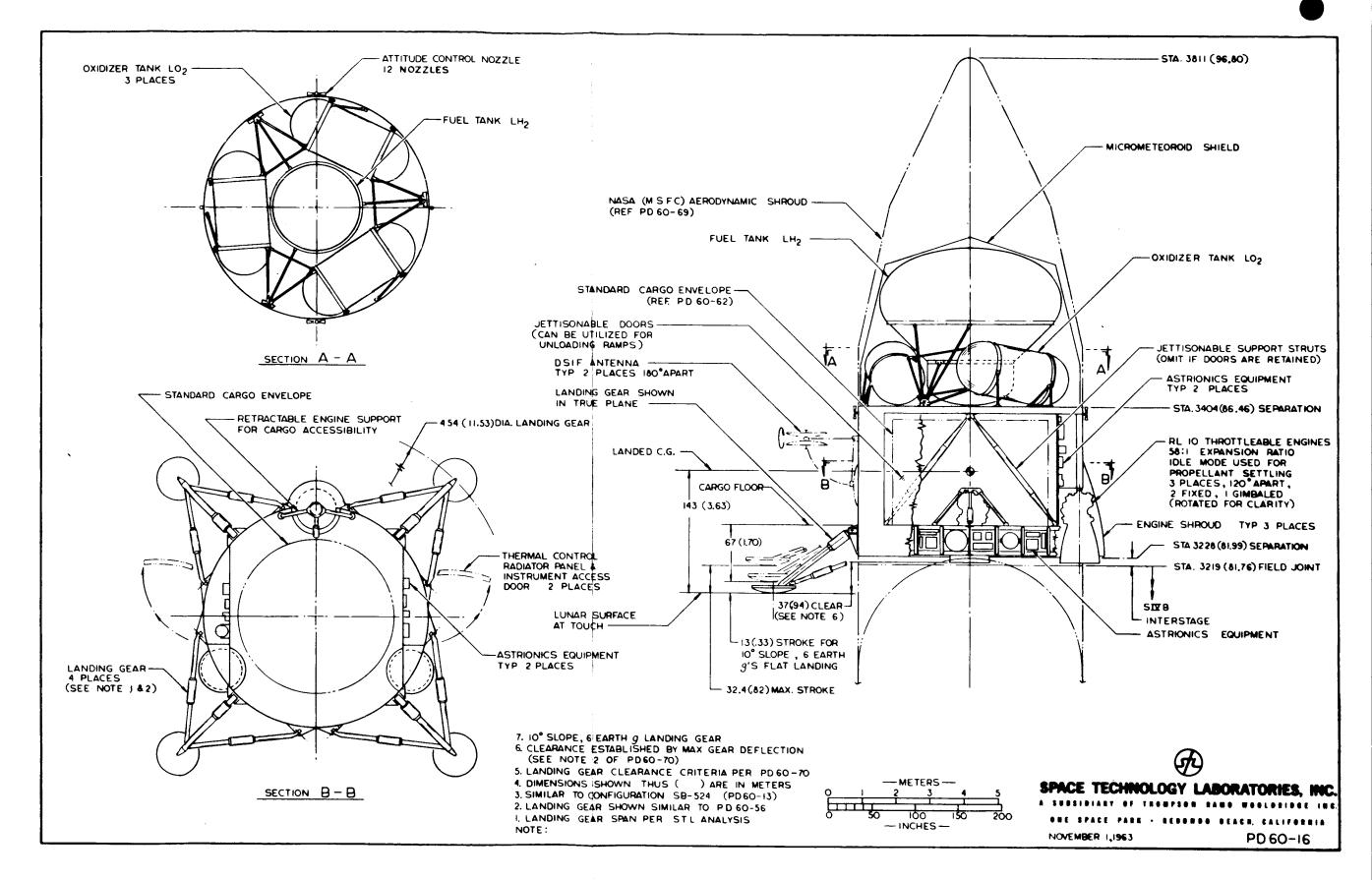


Figure 2-7. Tailored LLS, Single Stage, Low Cargo Configuration SB-529

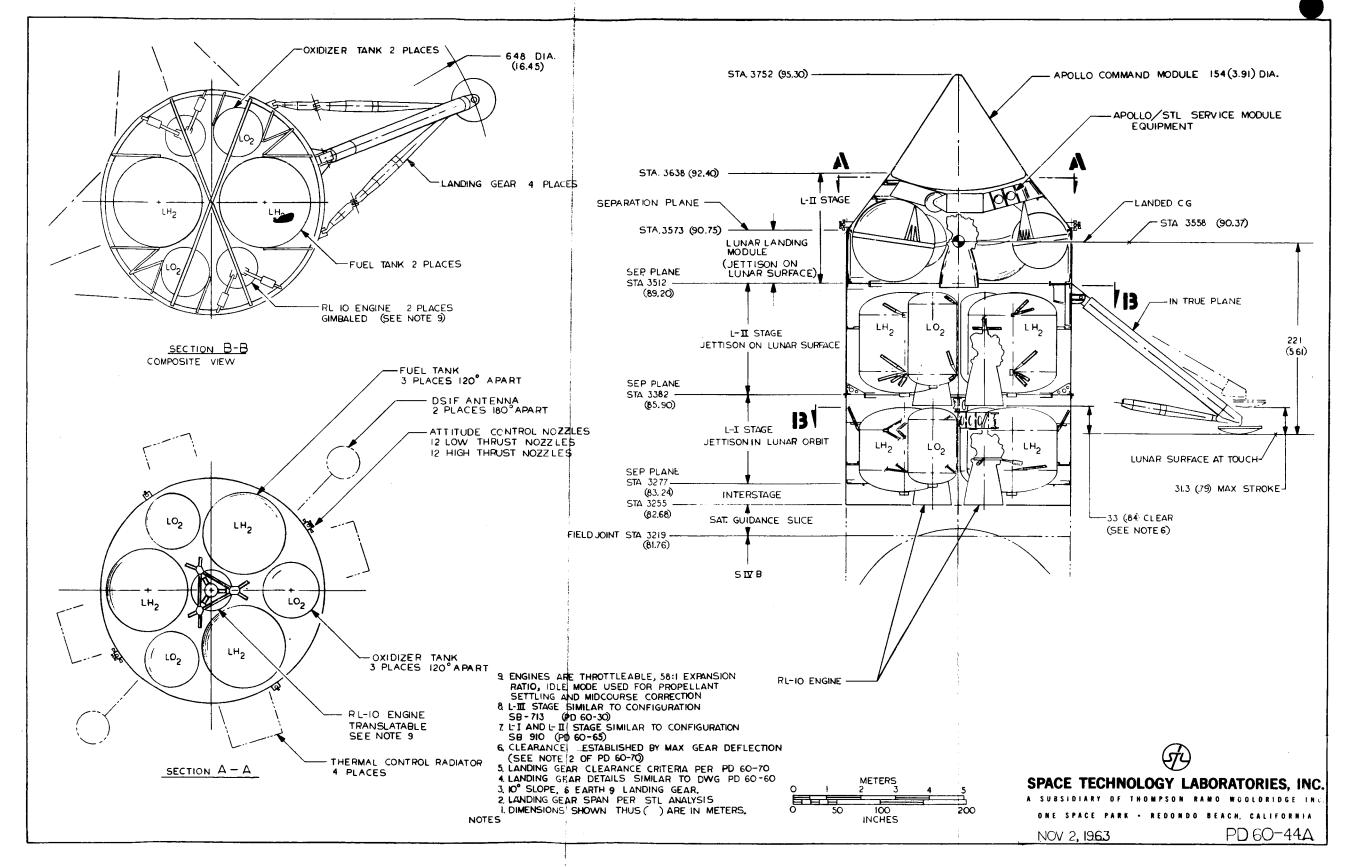


Figure 2-8. Hybrid, Three Stage, Manned (L-I and L-II Modular, L-III Tailored) - Configuration SB-908

without resulting in an overbalancing loss in vehicle performance. This would lead to an overall program advantage represented by a high confidence in meeting objectives on schedule and a high cost effectiveness.

The use of previously developed hardware in new programs is, of course, a well-established development program tenet. The MMM concept goes beyond this to apply multi-use to a complex interrelated subsystem represented by stage propulsion. Thus, the previous development applies not only on a component hardware level, but on a subsystem level to design and analysis, ground support equipment and operations, development testing, static testing, and flight test. This propagates into an elimination of additional system test facilities and system test vehicles which would otherwise be required to support propulsion testing.

To bring out the above considerations in concrete terms, development plans have been investigated relative to a modular pair and a tailored pair. A development program for the modular logistic space-craft has been formulated in some detail (Section 3.2). This is presented in schedule form in Figure 3-1 and by program task flow diagrams in Figures 3-2 through 3-5. Plans for a modular pair (Section 3.5) and a tailored pair (Section 3.6) are then developed using the elements of the logistics spacecraft program as a basis and with the same ground rules and assumptions. These plans are presented in schedule form in Figure 3-8 and 3-9.

Using these representative pair program plans, it is possible to see the implications of the module approach. The major effect is in total number of flight test vehicles and in the related facility requirements. These important considerations are shown in Tables 2-1 and 2-2. Application of the concept to a series of programs supporting various missions would evidently result in even more significant advantages for the modular approach. This of course would depend on actual program parameters. For example, the advantages from

Table 2-1. Flight Test Summary for Pair Programs

	Manned	ı	ı		ı	ı	ı					No	No	No	Yes	
	Apollo	I	,		í	i	ı					Semi-Live	Semi-Live	Live	Live	
Modular	L-III Guidance	οN	No		Yes	Yes	Yes					Yes	Yes	Yes	Yes	
	П-П	ı	ı		ı	ı	ı					Live	Live	Live	Live	
	L-II	Live Dummy	Dummy		Live	Live	Live					Live	Live	Live	Live	
	L-I	Live	Live		Live Live	Live	Live Live					Live Live	Live	Live	Live Live	
	Manned	ı		ı	ı	l	í		No No	No	No	No	No	No	Yes	
q	Apollo	ı	1	ı	ı	ı	ı		Dummy	Dummy	Dummy	Semi-Live	Semi-Live	Live	Live	
Tailored	Guidance	No	No	Yes	Yes	Yes	Yes		No	No	Yes	Yes	Yes	Yes	Yes	
	L-II	Dummy	Dummy	Live	Live	Live	Live		Dummy	Dummy	Live	Live	Live	Live	Live	
	L-I	Live	Live	Dummy Live	Live	Live	Live		Live	Live	Dummy Live	Live	Live	Live	Live	
E	Lype	Lob	Lob	Lob	Lob	Lob	Lob		Lob	Lob	Lob	Lob	Lob	Orbital	Orbital	
	Mission			oite	igo	T	•				pəu	u e J	N			

Table 2-2. Facility Requirement

Facility  1) Factory Assembly Stage Assembly Stations 2) Factory Systems Test and Refurbish Spacecraft Vertical Test Bays 3) Static Test	Tailored Logistics 8	Tailored Manned 8	Number Required Modular Logistics  8	Tailored Pair 16	Modular Pair 13
Stage Firing Capability  4) Development Flight Test WSMR Launch	4 2dual stands 1	2 dual stands	3 l dual stand l single stand l	8 4 dual stands	4 l dual stand 2 single stands 1*
5) Operational Launch Saturn V		1 1	1	7 2	7 7

multiusage of facilities can only be achieved when this multiusage is consistent with schedule demands.

The contractor arrangement for implementing the pair programs has been considered in relation to its effect on the development plans. For individually tailored approaches there would be no particular advantage in a single contractor, and each spacecraft would in general be contracted separately. For the modular approach, however, the realization of program advantages mentioned above is very dependent on transferring the achieved module development to any other MMM program. It is felt that this can only be done efficiently through keeping the same contractor for the module on all programs. Thus, if the total multiapplication development program represents a magnitude such that a single contractor is undesirable for both the stage and the module, a natural division is indicated. A separate module contractor would be established and the remaining spacecraft development work for the various applications would then be suitable for a single contractor or could be given to several contractors as desired.

For the multiapplication program that is to be carried out by a stage contractor and a separate module contractor there arises the question of module/stage integration. This has assembly, ground support, facility, system test, and launch operation considerations as well as the spacecraft hardware interface.

The removal of propulsion system design and integration from the stage contractor or airframe role represents a very significant effect. With the module contractor having design responsibility for the module equipment it is appropriate that he also have responsibility for the corresponding ground support equipment and operations. This means propellant transfer, gas transfer, propulsion checkout and control, etc., and leads to a major test operations role for the module contractor with facility implications. It also implies responsibility for all propulsion plumbing assembly and test that affects system

cleanliness or leakage control. This means a further major role for the module contractor in factory operations and stage acceptance. Thus, the stage contractor no longer represents a single overall responsibility for activities starting with final vehicle assembly, acceptance, and leading subsequently to system test and launch. Instead there will be well-defined roles and responsibilities for each contractor, with the module contractor having a strong associate role.

The physical installation of the module equipment into the stage structure poses a difficult working relationship interface between the two contractors. A conceptually attractive approach would be to deliver and install the module as an integral unit. However, the need to attach the many items of propulsion equipment directly to the stage or support structure makes this impractical. Furthermore, a detailed equipment replace/install capability on the part of the module contractor in regard to his equipment could not be avoided in any case as part of the subsequent system test and launch operations. Therefore, it was felt necessary to establish a joint assembly facility with considerable interrelation in the module and stage assembly activities.

The question of roles and responsibilities does not arise when a single contractor has the total task. On the other hand, the module contractor role would be relatively even stronger for the case when more than one stage contractor is involved in the total MMM program. For example, certain tasks might be given to the module contractor rather than to any stage contractor in order to facilitate wide application across the total program.

#### 2.3 COST ANALYSES

Detailed cost estimates have been prepared for eight lunar direct flight vehicles. Of the sixteen possible combinations of manned and logistics vehicle pairs which can be made from these eight vehicles, nine pairs were considered of sufficient interest that the costs of developing the pairs were estimated. The cost estimates include both

development and recurring costs. Each program estimate includes costs for various numbers of operational vehicles up to a maximum of sixteen. In the preparation of these estimates, the reduction in vehicle fabrication costs made possible through the experience gained as additional vehicles are constructed has been taken into account by means of a 90 percent learning or experience curve.

A summary of the cost information for the programs investigated is presented in Table 5-1 and graphical summaries for the various pairs are shown in Figures 5-1, 5-2, and 5-3.

Prior to estimation of these costs, program plans were prepared for each configuration. In the case of configurations which incorporate modules, the program plans were based upon development of the logistics and manned vehicles as a pair. This type of planning made possible appreciable reductions in development and facility costs as well as in the number of vehicles required for development. However, this being the case, when it is desired to estimate the costs of various pair combinations, the costs shown in Table 5-1 cannot be added directly to get pair costs in every case. When modular configurations are combined with non-modular configurations or with configurations in which the module tanks are appreciably different in size, additional cost terms must be included. These terms are included in the figures mentioned above.

Since the cost information contained in this report is merely an input to a figure-of-merit which is used to evaluate the various pair combinations (Volume I) the relative magnitudes of the costs will not be discussed in detail here. However, certain major cost factors can be pointed out.

In the configurations considered in this report, the modular concept was found to make possible cost reductions of approximately \$60 million in a program in which the total cost was approximately \$400 million. This reduction was possible only if it was planned that

the module should be developed in the other vehicle comprising the pair. The total pair development cost was on the order of \$800 million.

The cost of developing a module for a typical vehicle configuration was estimated to be \$32 million. This number includes only module and GSE development costs and does not reflect the reductions in facility, GSE and test vehicle requirements which result when a previously-developed module is utilized in a configuration.

The cost reductions made possible through the use of the modular concept will be offset by other features of the design if care is not exercised. For example, expenses incident to the additional stage when a three-stage modular configuration is compared with a two-stage tailored configuration tend to outweigh the advantages obtained through the use of the module.

The cost decrements obtained by utilizing the modular concept may be approximately doubled if stage commonality as well as module commonality are achieved.

The hybrid pair was the lowest cost pair examined when complete first stage commonality was assumed. This pair was also attractive from a cost standpoint even when stage commonality was not assumed. In the latter case, however, the costs of the pairs composed of the tailored single stage, and either the hybrid manned or the tailored manned, are also very comparable.

The use of Saturn IB boosters for the development flight test program as requested by MSFC, instead of the Little Joe II boosters as originally programmed, has two major effects:

- a) The costs of a pair program are increased by approximately 50 percent or more as a result of using these more expensive boosters.
- b) The cost reductions made possible through the use of the module are greatly amplified as the result of the reduced number of test flights (hence boosters) required when the modular concept is utilized.

## 3. DEVELOPMENT PLANS

#### 3.1 GENERAL

## 3 1 1 Multimission Module Concept

A large number of space missions are currently under consideration for the near future based upon use of the Saturn V or the Saturn IB as a launch vehicle. Representative ones may be listed as follows:

# Mission Launch Vehicle

Lunar Logistic Spacecraft Lunar Personnel Spacecraft Apollo Service Module High Energy Probes Planetary Orbiter

Saturn V

Planetary Probe
Synchronous Orbiter
Orbital Transtage
Gemini Circumlunar
Lunar Logistic Spacecraft
Apollo Circumlunar
Apollo Reentry Test

Saturn IB

In defining vehicle stages for the above missions, the LO<sub>2</sub>/LH<sub>2</sub> RL10A rocket engine is a natural choice because of its good performance and advanced state of development. When this commonality is coupled with the characteristics of the two launch vehicles it is seen that a family of stages utilizing a common thrust level can be defined for these missions, with propellant requirements varying over only a limited range. The studies of Reference 3-2 have sought to exploit this situation by defining a multimission module (MMM) that is adaptable to the various propellant loadings required, yet maintains a significant core of common hardware and design features for all mission applications. The present discussion explores the development considerations relating to this MMM concept.

As seen from the description in 2.1, the stage propulsion system (engines, propellant feed, pressurization, tanks, etc.) represents the major part of the MMM. The module concept, however, emcompasses the use of common elements outside of propulsion as well. To achieve the different propellant loadings, the cylindrical lengths of the LO<sub>2</sub> and LH<sub>2</sub> tanks are varied (and hence the stage length) but not the tank diameters, which allows the tank bulkheads to be kept unchanged. The items that are mission-peculiar will change, of course, from application to application, but the total changes required are naturally much less than for a completely new and different stage design.

## 3.1.2 Development Considerations

The underlying idea in the MMM approach is that the use of such a major common element across several mission applications can lead to significant simplifications in the overall development effort, without resulting in an overbalancing loss in vehicle performance. This then would lead to an overall program simplification with a higher confidence in meeting objectives on schedule and with a higher cost effectiveness.

The use of previously developed hardware in new programs is, of course, a well-established development program tenet. The MMM concept goes beyond this so as to apply multiuse to a complex interrelated subsystem represented by stage propulsion. Thus, the previous development applies not only on a component hardware level, but is applicable on a subsystem level to design and analysis, ground support equipment and operations, development testing, static testing, and flight test. This propagates into an elimination of additional system test facilities and system test vehicles that would otherwise be required to support propulsion testing.

There is an additional effect that is difficult to express quantitatively but nonetheless may be very important. This is a reduction in program confusion because of fewer major test failures, design deficiencies, human operating errors leading to major damage, etc. Such difficulties are not generally included in program planning or costs because they are intangible. However, experience has shown that development programs of this nature experience such things, especially in the areas of the propulsion system. Thus, in an MMM program high proficiency in operations and high reliability in equipment will be realized in the follow-on programs resulting in these programs having less uncertainty and confusion than would be the case if they represented newly developed propulsion systems.

There are many qualitative considerations that favor an MMM approach. To make these more concrete it is necessary to define appropriate development programs to a certain level of detail, and to compare them with programs corresponding to a tailored approach. This will be done in the following sections, but first it is appropriate to identify the contractor roles associated with development of such a family of MMM spacecraft.

## 3.1.3 Identification of Contractor Roles

The simplest contractor arrangement for a spacecraft development is to have a single spacecraft contractor. This has obvious organizational advantages, but there are two general considerations that tend to make it impractical. First, the need for specialization leads to a separate guidance contractor, engine contractor, etc., to get a high proficiency in the associated specialties. Second, for a very large vehicle development program the task is considered too much for a single organization, and a convenient breakdown is found in order to give the job to several contractors. Some arrangement for integrating the work of the several vehicle contractors is then required.

In considering the spacecraft development job for the family of space missions (Paragraph 3.1.1.), the need for specialty contractors is not affected by the modular versus tailored considerations, so this discussion will be concerned only with the stage development task exclusive of such specialties. For individually tailored approaches there is no particular advantage in a single contractor. Each spacecraft would in general be contracted separately. For the MMM approach, however, the realization of program advantages mentioned in Paragraph 3.1.2 is very dependent on transferring the achieved module development to the other programs and this can be done efficiently only through keeping the same contractor. Thus, the use of a single spacecraft contractor seems to be called for. However, if the total multiapplication development program represents a magnitude such that a single contractor is undesirable, a natural division is possible. As the need for transfer of development knowledge across the various applications relates basically to the module, it is this work that can be broken out as a task for a single contractor across all the MMM programs. The remaining spacecraft development work for the various applications would then be suitable for a single contractor or could be given to several contractors as desired.

In the MMM programs to be discussed we shall assume a single contractor (called the module contractor) to be responsible for development of the module in all programs. For the limited number of space applications to be covered we shall assume all the remaining stage development to be done by a single contractor, who will be called the "stage contractor." An explicit identification of a separate module contractor is simply to gain more generality in the discussion. If it is desirable to combine the stage and modular contractor tasks into a single contractor responsibility this easily can be visualized from the discussion presented. All the basic tasks remain the same. Also, there is considerable simplification to be realized for the program when the formal equipment and working relationship interface is eliminated.

## 3.1.4 Module/Stage Integration

For the multi-application program that is to be carried out by a stage contractor and a separate module contractor there arises the question of module/stage integration. This has assembly, ground support, facility, system test and launch operation considerations, as well as the spacecraft hardware interface.

The removal of propulsion system design and integration from the stage contractor or airframe role represents a very significant effect. With the module contractor having design responsibility for the module equipment it is appropriate that he also have responsibility for the corresponding ground support equipment and operations such as propellant transfer, gas transfer, propulsion checkout and control, etc., and leads to a major test operations role for the module contractor with facility implications. It also implies responsibility for all propulsion plumbing assembly and test that affects system cleanliness or leakage control. This means a further major role for the module contractor in factory operations and stage acceptance. Thus, the stage contractor no longer represents a single overall responsibility for activities starting with final vehicle assembly and acceptance, and leading subsequently to system test and launch. Instead, there will be well-defined roles and responsibilities for each contractor with the module contractor having a strong associate role.

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The question of roles and responsibilities does not arise when a single contractor has the total task. On the other hand, the module contractor role would be relatively stronger for the case when more than one stage contractor is involved in the total MMM program. For example, certain tasks might be given to the module contractor rather than to any stage contractor in order to facilitate wide application across the total program.

#### 3.2 MODULAR LOGISTIC SPACECRAFT PROGRAM

The development of a modular logistic spacecraft represents the pivotal program for the current study. Historically, it was through investigation of this application that the modular concept came into focus, and a great deal of information has been developed in this area (References 3-1 and 3-2). In addition to forming part of the direct flight pair, its development separately from the personnel carrier has considerable current interest. Thus, we will use it as a basis for developing and discussing the characteristics of a modular program. Because it has two stages, this program allows us to consider the application of the modular concept within a single program. We will then build up the modular pair program using the logistic program elements as a basis.

In keeping with the work statement it was considered appropriate to utilize the LLS program presented in Reference 3-1 as a basis for developing the modular logistic program. The basic program elements were identified where applicable and subjected to redefinition based on the two-contractor approach discussed in Section 3.1. Differences between the two programs will be discussed in Section 3.4. The same ground rules as for the LLS program were utilized as follows:

- a) Forty-nine months to first operational launch
- b) First operational mission planned for lunar landing with full payload
- c) Final drawing release for structural subsystems, 15 months; for critical subsystems, 18 months
- d) Fabrication start for first complete vehicle, 16 months
- e) Fabrication requires 6 months
- f) Assembly requires 7 months
- g) Acceptance system test plus transport, 1-1/2 months
- h) Preflight static firing 1-1/2 months
- i) Refurbish and final acceptance system test, 1-1/2 months

  An overall schedule for the program based on the above ground rules is shown in Figure 3-1.

To define the program and bring out important aspects of the modular approach, a series of flow diagrams is presented in Figures 3-2 through 3-5. These show the relationships between the various program tasks which have been coded to refer to corresponding task descriptions presented in Figure 3-2 through 3-5. The tasks associated with the module contractor alone are given in Figure 3-3, and those for the stage contractor alone in Figure 3-4. Those carried out jointly by both contractors for assembly and system test are covered in Figure 3-5.

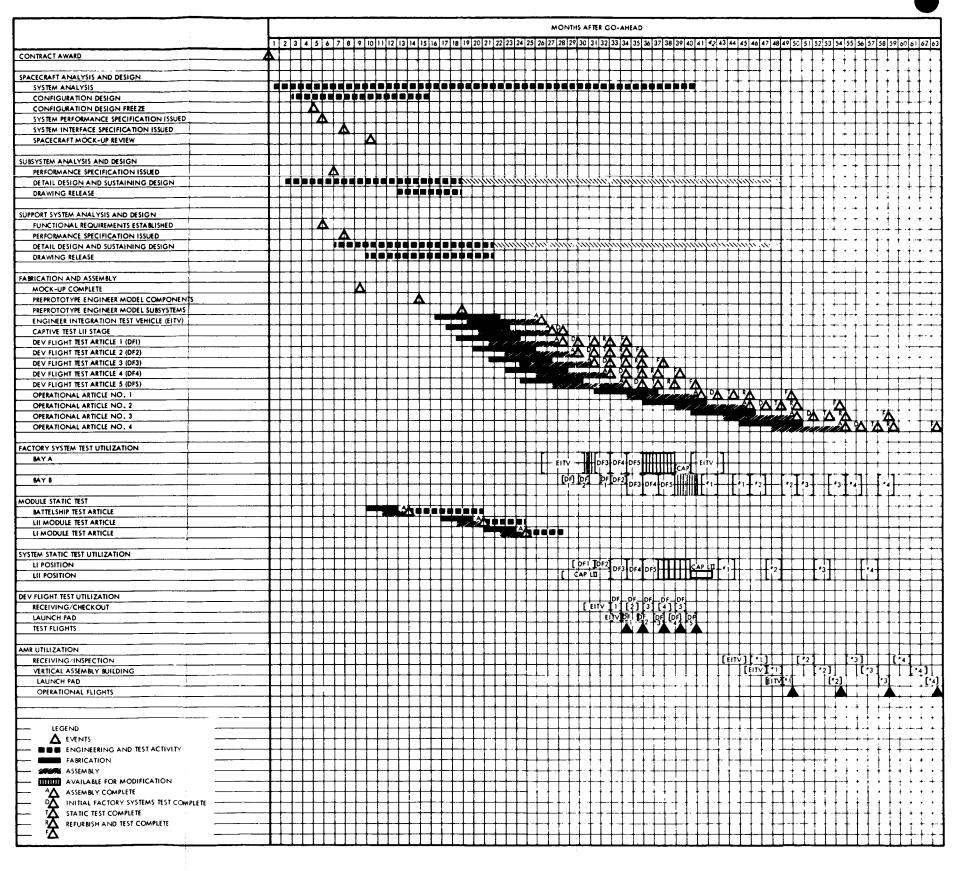


Figure 3-1. Program Schedule
Modular Lunar Logistics Spacecraft

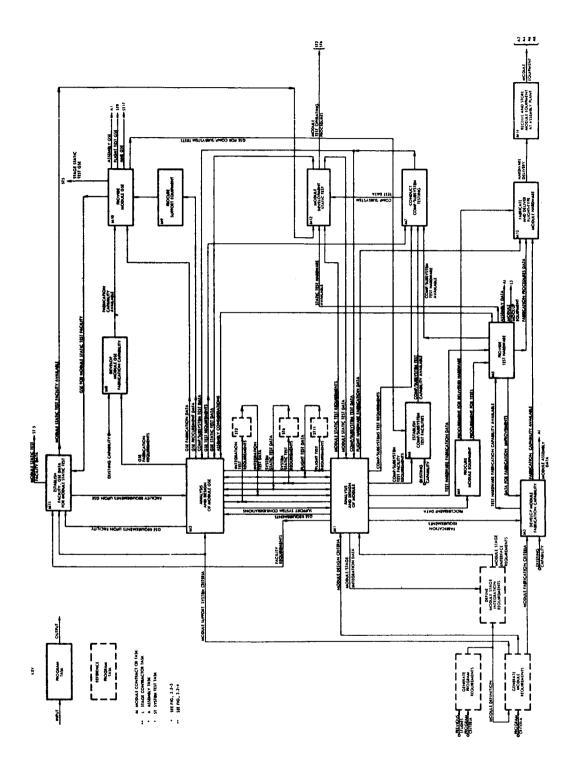


Figure 3-3. Program Task Flow Diagram Module Development (Module Contractor)

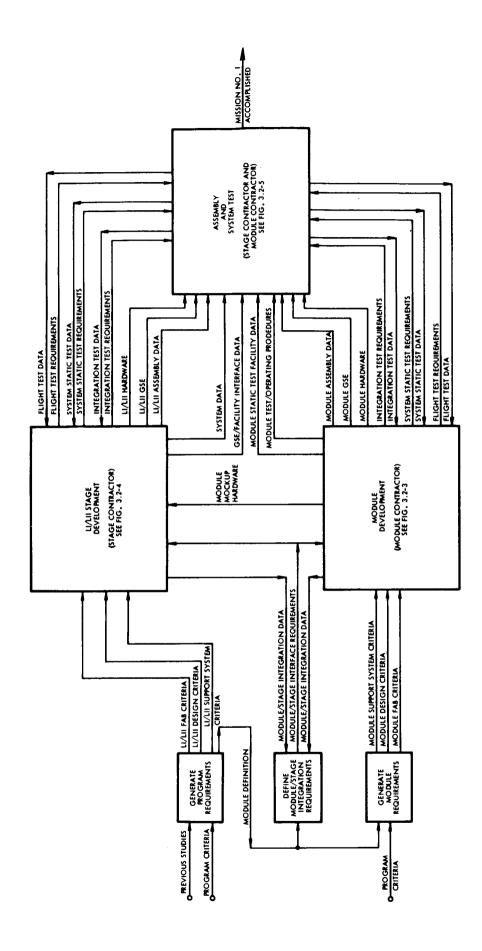


Figure 3-2. Program Task Flow Diagram Modular Lunar Logistic Development Program

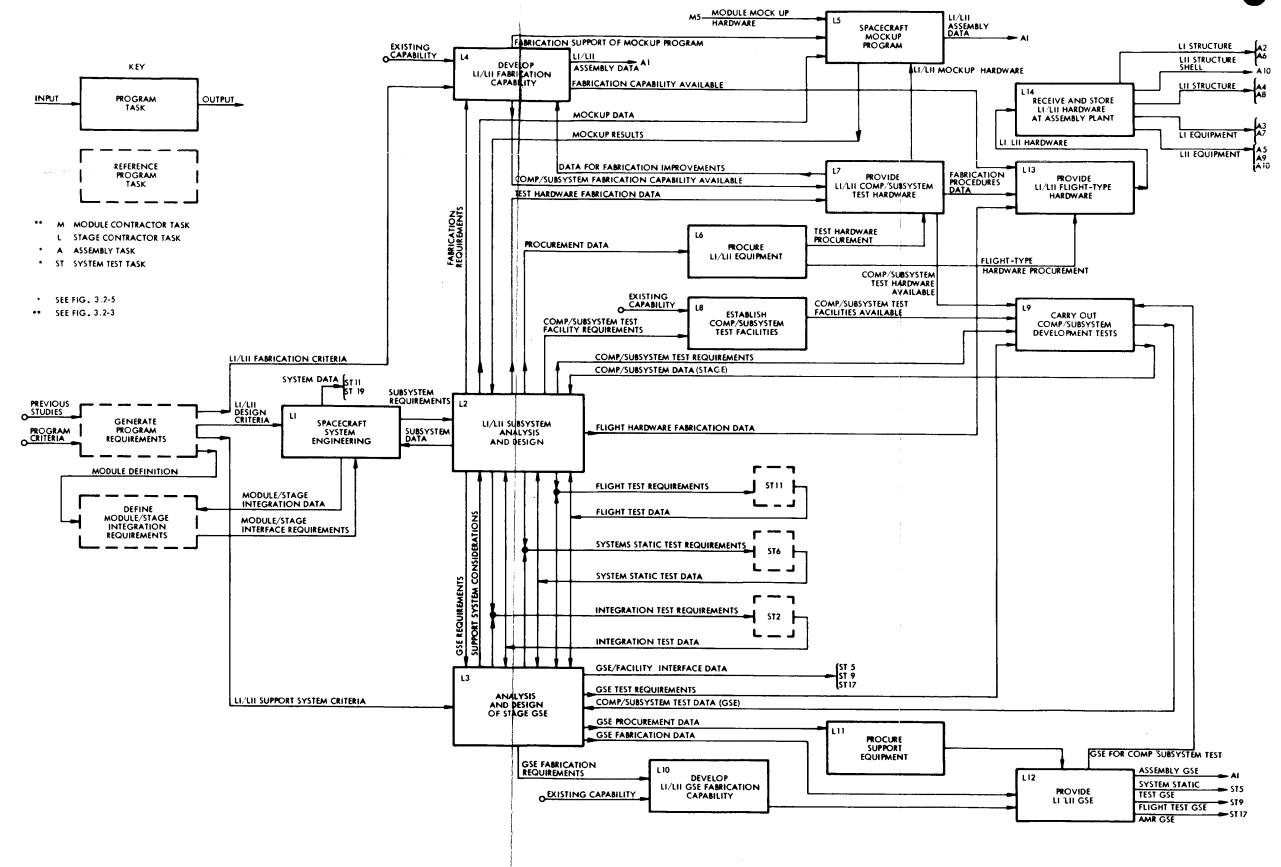


Figure 3-4. Program Task Flow Diagram L-I/L-II Stage Development (Stage Contractor)

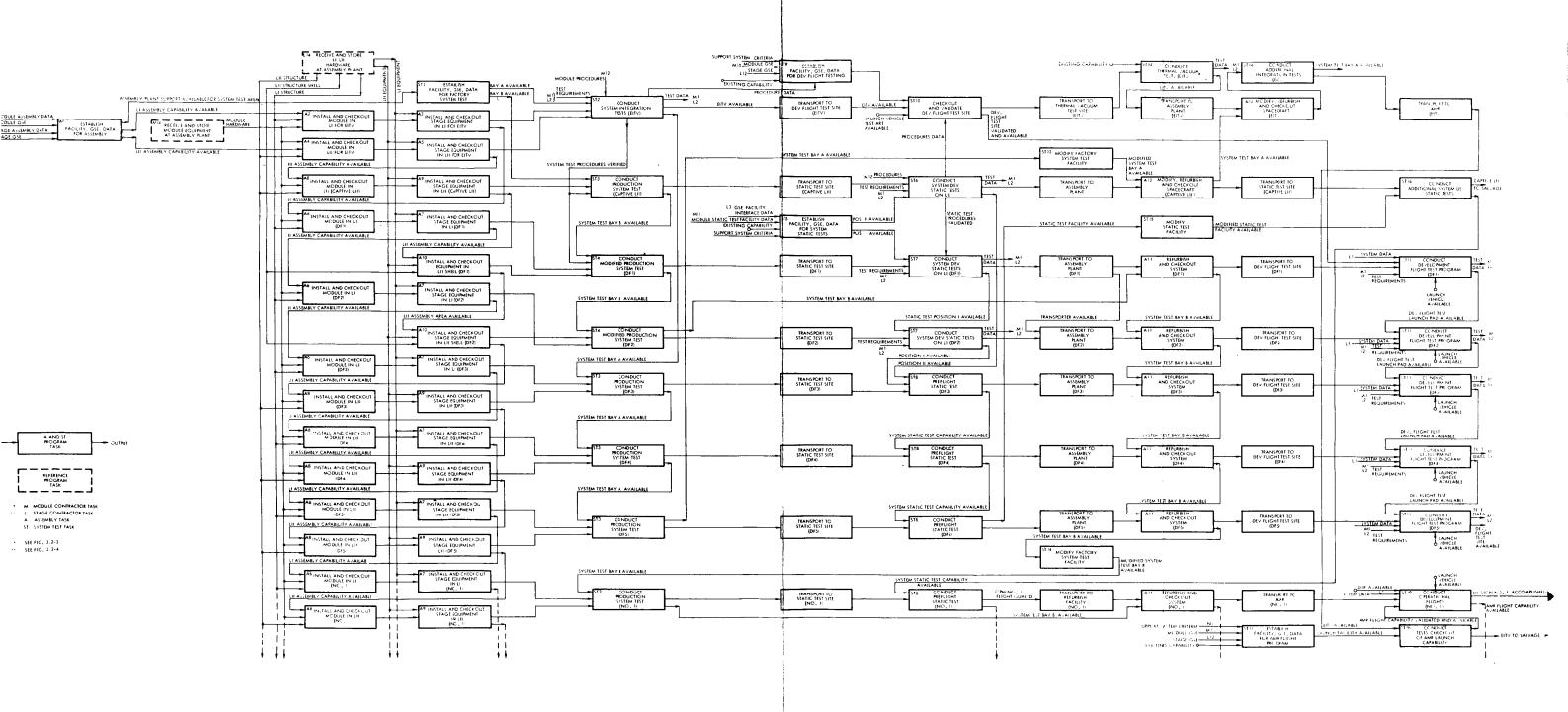


Figure 3-5. Program Task Flow Diagram
Assembly and System Test

### 3.2.1 Module Development Tasks (M1)

### 3.2.1.1 Analysis and Design of Module

With the module design criteria as a basis, the module contractor will carry out the analysis and design of the module equipment. In keeping with the description of the module given in Section 2.1, the following design tasks will be accomplished:

- a) Structural design of  $LO_2$  and  $LH_2$  tanks
- b) Insulation for  $LO_2$  and  $LH_2$  tanks
- c) Thermal control of storable tankage, functioning components, etc.
- d) LO<sub>2</sub> and LH<sub>2</sub> propellant feed, fill, drain system
- e) LO<sub>2</sub> and LH<sub>2</sub> tank pressurization
- f) LO<sub>2</sub>/LH<sub>2</sub> propellant utilization system
- g) Main engine integration
- h) Engine gimbaling
- i) Reaction control propulsion
- j) Electrical harness
- k) End instruments

A considerable amount of effort in the above areas is associated with technical support and the generation of input for other program activities. This includes test requirements and plans, fabrication and assembly considerations, procurement data, support equipment requirements, facility criteria, stage/module interface definition, test procedures, drawings and specifications, etc. In addition, test results will be evaluated and taken into account in finalizing the design.

## 3.2.1.2 Analysis and Design of Module GSE

The module contractor will be responsible for all GSE directly associated with module equipment. This includes LO<sub>2</sub> transfer, LH<sub>2</sub> transfer, storable propellant transfer, gas transfer, checkout/control of all fluid transfer operations, pressurization and propellant feed checkout/control, engine checkout/control, purge and leak check operations, mechanical inspection/alignment/checkout, assembly/installation, handling, and shipping/transporting.

In addition to design of GSE associated with the above functions, a considerable associated effort is required for technical support and generation of input for other program activities. This includes test requirements and plans, fabrication considerations, procurement data, module/GSE interface definition, facility criteria, operating procedures, interface with Saturn facility and integrated checkout, drawings and specifications, etc. Also, test results will be evaluated and taken into account in finalizing the design.

## 3.2.1.3 Development Module Fabrication Capability

Tool design will be accomplished to develop all jigs, dies, manufacturing aids, etc., required for all module hardware end items as described in Paragraph 3.2.1.13. The design of special electrical test equipment used in the factory is included. Also, the fabrication effort necessary to manufacture all jigs, dies, manufacturing aids, and special test equipment is part of this task.

### 3.2.1.4 Procurement Module Equipment

A "make-or-buy" policy will be established in regard to module equipment. It is expected that accordingly many components will be procured from vendors rather than fabricated by the module contractor. In particular, previously developed components will be utilized to the maximum extent.

### 3.2.1.5 Provide Test Hardware

The necessary hardware to support the component/subsystem testing described in Paragraph 3.2.1.7 and to support the module static testing described in Paragraph 3.2.1.12 will be provided on a timely basis. In addition, this task provides two other developmental objectives as follows:

- a) Provides experience and data for verifying and improving the factory fabrication equipment and procedures. This includes quality assurance and acceptance test procedures for the delivered items.
- b) Develops the module assembly process to be utilized at the stage assembly plant as described in Paragraph 3.2.4.2.1 of Paragraph 3.2.3. This is accomplished in the assembly of the module static test articles.

### 3.2.1.6 Establish Component/Subsystem Test Facilities

Facilities will be required for carrying out the test program described in Paragraph 3.2.1.7. This involves a cold flow laboratory capability for propulsion component and subsystem tests, a structural test facility including provisions for tank pressure testing, a reaction control system firing facility, and miscellaneous general purpose laboratory test facilities.

### 3.2.1.7 Conduct Component/Subsystem Testing

Component and subsystem testing will be carried out to investigate and validate the design to the maximum extent practical prior to static testing and flight testing. This testing includes the following elements:

3. 2. 1. 7. 1 Propellant/Pressurization Cold Flow Testing. Component tests will be conducted to include operation under maximum and minimum expected temperatures and pressures as well as other pertinent environmental conditions. Tanks will be filled and drained under realistic

conditions, utilizing actual ground system propellant transfer hardware. Standby conditions investigated will include tank venting, check of insulation purging effectiveness, etc. Procedures for factory and system test operations will be developed and the corresponding GSE tested in conjunction with the spacecraft elements. Outflow tests under simulated engine firing conditions will be carried out to investigate tank pressure time history, propellant utilization system operation, tank emptying outflow characteristics, equalization between tanks, etc. Tank calibration data and procedures will be developed.

3.2.1.7.2 <u>Tank Structural Tests</u>. All tanks will be tested to confirm their ability to meet design requirements with adequate safety. Tank attachment points will be static tested. Three samples of each pressure vessel will be subjected to proof pressure cycling, burst, and vibration tests as appropriate. Effects of temperature will be included.

The production test process applicable to each tank will be defined.

3.2.1.7.3 Thermal Control Tests. Cryogenic control tests will be conducted to develop optimum propellant tank insulation designs; the insulation efficiency as applied to a prototype portion or a scaled model will be evaluated. The insulation is to be applied with developed application techniques and tested under simulated environmental conditions of temperature and pressure. Outgassing and venting characteristics, and systems to eliminate prelaunch frost formation in the propellant tank insulation are to be investigated. The conductive heat flow between the tanks and the structure will be measured and evaluated.

Jet impingement tests will be conducted to determine structural effects of the reaction control jets. In conjunction with the stage contractor, a series of vacuum firings are to be made at an adequate facility (AEDC) to determine the thermal and structural effects of the reaction control jet exhausts. Engines are to be fired with the representative surrounding structure. Temperature, pressures, heating rates, and ablation rates are to be measured.

The operation of any thermal control equipment such as heaters will be tested as part of the associated component or subsystem tests where environmental conditions are simulated.

3.2.1.7.4 Reaction Control Tests. Reaction control rocket engine development tests will be conducted if off-the-shelf hardware is not available. Design verification and reliability testing will be achieved by a series of firings covering the range of expected propellant feed conditions. The storable feed system design will be tested and verified. Components will be operated and evaluated in propellant flow bench tests. The complete reaction control system will be fired and its performance and repeatibility determined.

Propulsion system qualification type tests will be conducted to include the following:

- a) Full duration tests under altitude conditions
- b) Malfunction/limits/peripheral tests for high and low voltage, feed pressure, and mixture ratio (if applicable) each at maximum and minimum thrust
- c) Environmental tests with operation after exposure to all expected conditions.

Testing of the associated GSE will be conducted. This will include operation of checkout equipment with the propulsion system and operation of propellant loading equipment during the reaction control system test programs.

3.2.1.7.5 Qualification Program. A production flight model of each component not previously qualified, or qualified as part of a subsystem, will be subjected to formal environmental qualification tests. The performance of the unit will be evaluated before and after exposure to the environmental limits specified. During the qualification tests, power and simulated input stimuli will be supplied as appropriate in order to

evaluate the unit under operating conditions. The environmental qualification tests are expected to include thermal-vacuum, vibration, shock, humidity, acceleration, and possibly radiation. Electro-interference tests will be specified as part of the environmental qualification test program.

### 3.2.1.8 Develop Module GSE Fabrication Capability

A task similar to Paragraph 3.2.1.3 is required to develop the capability for fabrication of module GSE.

### 3.2.1.9 Procure Support Equipment

Just as in Paragraph 3.2.1.4, it is expected that procurement rather than fabrication will be required in many instances so as to utilize to the maximum previously developed support equipment.

### 3.2.1.10 Provide Module GSE

The module contractor will supply all GSE for the support functions described in Paragraph 3.2.1.2. Non-deliverable prototype equipment will be used in component/subsystem testing and at the module static test facility to provide early test experience. Delivered units will be utilized at the assembly plant (Paragraph 3.2.4.1), the stage static test facility (Paragraph 3.2.3.5), the development flight test site (Paragraph 3.2.3.9), and at the AMR launch complex.

### 3.2.1.11 Establish Facility, GSE, Data for Module Static Test

A static test facility will be required for carrying out the test program described in Paragraph 3.2.1.12. Accommodation of only one module test article at a time is required. The facility design will allow for variations in module geometry that may be required for any of the contemplated mission applications. A complete set of GSE to support the module system static testing will be required. Prototype GSE will be utilized initially and updated as required to represent the final configuration.

#### 3.2.1.12 Module Development Static Test

The module development static test program will provide development and design verification data by operating the complete module and its ground support system under firing conditions. A basic component and subsystem test program will be defined and implemented within the framework of Paragraph 3.2.1.7 as a prerequisite to the initiation of module static testing. Prototype hardware will be utilized in a "battleship" test article to allow for early testing. As flight-type hardware becomes available it will be utilized in fabricating two module system test articles - an L-I type and an L-II type.

The module system test articles will consist of the module equipment mounted in a convenient structural framework to provide support points with the proper stage geometry. The two flight-type test articles will utilize actual tank and engine support structures as well as actual support brackets, etc., for the other module equipment.

In addition to thorough testing of the module system under firing conditions, a number of non-flight objectives will be accomplished as follows:

- a) Verify propellant loading system
- b) Verify standby conditions such as venting, insulation purging, etc.
- c) Determine propellant loss under maximum temperature
- d) Verify storable propellant loading system
- e) Verify helium loading system
- f) Verify prefiring servicing and checkout operations
- g) Verify postfiring operations for system test.

During the module static test program, data will be fed back to the design groups for inclusion in the final design. Procedures for reliability reporting and quality assurance failure analysis will also be included to utilize data for systems evaluation as appropriate to the hardware being tested.

### 3.2.1.13 Fabricate and Deliver Flight-Type Module Hardware

Flight-type module hardware will be required for spacecraft system tests and operational articles. The system test articles may be listed as follows:

Article	Number of Modules
EITV	2
Captive L-II	1
DFl	1
DF2	1
DF3	2
DF4	2
DF5	2
	11

The module hardware will be delivered as subassemblies and components rather than as a single integral unit. A representative list of delivered items constituting a single module are listed below:

<u>Item</u>	Number Required
LO <sub>2</sub> tank	2
LH <sub>2</sub> tank	2
RL10A rocket engine	2
LO <sub>2</sub> propellant feed kit	1
LH <sub>2</sub> propellant feed kit	1
Reaction control groups	l set
Storable propellant feed kit	1
Pressurization kit	1
Electrical harness kit	1
Gimbaling system kit	2

Specifications and acceptance procedures will be established for each end item, including components delivered as spares.

### 3.2.1.14 Receive and Store Module Equipment at Assembly Plant

An area at the assembly plant will be set aside and utilized by the module contractor to receive and store module equipment as described in Paragraph 3.2.1.13. This equipment will be utilized in stage assembly and to provide spares support at the assembly plant. Receiving inspection and limited testing will be accomplished at this area, but all defective items will be returned to the module contractor's plant for repair or disposition.

### 3.2.2 Modular Stage Development Tasks

### 3.2.2.1 Spacecraft System Engineering

This task represents the engineering effort involved in overall system design and in the specification and control of subsystem interface

parameters within a framework established by the program integration responsibility. It contains such items as configuration analysis, system guidance, mission control, performance and trajectory analysis, system definition, subsystem requirements, weights control, and technical liaison.

A key set of the above system development tasks consists of specifying and implementing all system and subsystem interfaces in detail. On the system level, interface specifications will be needed for the spacecraft/launch vehicle, spacecraft/payload, spacecraft/DSIF, spacecraft/launch complex, module/stage, etc. Below the system level, separate interface specifications must be written for each major subsystem element.

A considerable amount of performance and trajectory analysis is required. Propellant requirements must be determined for various contemplated configurations and modes of operation. Studies must be conducted to determine the earth injection and final conditions for a wide range of parameters, so as to satisfy the various system constraints. Parametric powered flight studies will be needed for trajectory shaping, throttling programs, approach elevation angle determination, etc. In addition to support of operational missions, the performance and trajectory analysis effort must support the developmental flight tests.

During the development program, mass properties data must be determined and disseminated for the complete spacecraft and sub-assemblies. This mass properties data will include hardware and propellant weights, centers of gravity, moments of inertia, products of inertia, and mass distributions. The data will be published in periodic reports to using organizations (i.e., structures, dynamics, flight mechanics, etc.), to project personnel, and to the contracting agency.

Guidance analysis (which could be the responsibility of an

associate guidance contractor) will include definition of guidance techniques and system mechanization, error analysis, determination of performance requirements of guidance components, defining and programming detailed guidance equations, preflight calculation of guidance constants, test planning and evaluation, etc.

### 3.2.2.2 L-I/L-II Subsystem Analysis and Design

With the appropriate subsystem design criteria and applicable interface requirements of L-I as a basis, the stage contractor (or a designated associate contractor in the case of guidance) will carry out analysis and design for six areas of responsibility.

## 3. 2. 2. 1 <u>Structural Design</u>. Structural design responsibilities will include:

- a) Loads definition
- b) L-I and L-II basic structure
- c) Adapter structures
- d) Stage separation
- e) Payload mounting
- f) Landing analysis
- g) Landing gear design
- h) Module support structure in L-I and L-II
- i) Deployable mechanisms
- j) Equipment installation
- k) Micrometeoroid shielding.

## 3. 2. 2. 2. Thermal Control. Thermal control responsibilities will include:

- a) Passive thermal control of non-dissipative equipment
- b) Active thermal control of electronic equipment
- c) Module/Stage thermal interface definition
- d) Thermal analysis of tank supports
- e) Definition of thermal environment from engine exhausts
- f) Aeroheating considerations.

## 3.2.2.3 Attitude Control System. Responsibilities in this area are:

- a) Reaction control system for coast, non-thrusting orientations and engine idling mode operation
- b) Thrust vector control system for main engine firings
- c) Guidance/Controls interface mechanization.

## 3.2.2.4 Guidance Equipment. Guidance equipment includes:

- a) Inertial measurement unit
- b) Spacecraft computer and associated input/output
- c) Terminal sensors.

# 3.2.2.5 <u>Communications and Telemetry</u>. This area involves responsibility for:

- a) Antennas and associated wave guides
- b) DSIF transponder
- c) Command decoder
- d) Telemetry/TV link equipment.
- 3.2.2.2.6 <u>Electrical System</u>. Electrical system responsibilities include:

- a) Power generation
- b) Power regulation and control
- c) Power distribution
- d) Signal distribution.

A considerable amount of effort in the above areas is associated with technical support and generation of input for other program activities. This includes test requirements and plans, fabrication and assembly considerations, procurement data, support equipment requirements, facility criteria, test procedures, drawings and specifications, etc. In addition, test results will be evaluated and taken into account in finalizing the design.

### 3.2.2.3 Analysis and Design of Stage GSE

The stage contractor will be responsible for all spacecraft GSE not directly associated with the module. This includes:

- a) Subsystem Checkout/Control (attitude control, guidance, electrical, communications telemetry, ordnance, range safety)
- b) Stage Control for system test
- c) Spacecraft Control for launch
- d) Alignment of guidance platform and sensors
- e) Electronic Equipment Environmental Control
- f) Electrical Ground Power
- g) TV Command Station
- h) Transportation (stage transporters, shipping containers)
- i) Assembly Equipment (work platforms, handling, master gages, weight and center of gravity determination fixture)
- j) Ground Umbilicals for stage equipment.

In addition to design of GSE associated with the above functions, a considerable associated effort is required for technical support and generation of input for other program activities. This includes test requirements and plans, fabrication considerations, procurement data, spacecraft/GSE interface definition, facility criteria, operating procedures, interface with Saturn facility and integrated checkout, drawings and specifications, etc. Also, test results will be evaluated and taken into account in finalizing the design.

### 3.2.2.4 Develop L-I/L-II Fabrication Capability

Tool design will be accomplished to develop all jigs, dies, manufacturing aids, etc., required for all stage hardware items. The design of special electrical test equipment used in the factory is included. Also, the fabrication effort necessary to manufacture all jigs, dies, manufacturing aids, and special test equipment is part of this task.

### 3.2.2.5 Spacecraft Mock-Up Program

A full-size spacecraft mock-up will be developed early in the program in order to support a formal design review in the tenth month after contract go-ahead. In addition, the mock-up will be utilized to establish equipment installation design and to verify physical compatibility of systems as installed.

### 3.2.2.6 Procure L-I/L-II Equipment

A "make-or-buy" policy will be established in regard to L-I/L-II equipment. It is expected that accordingly many components will be procured from vendors rather than fabricated by the stage contractor. In particular, previously developed components will be utilized to the maximum extent.

### 3.2.2.7 Provide L-I/L-II Component/Subsystem Test Hardware

The necessary hardware to support the component/subsystem testing described in Paragraph 3.2.2.9 will be provided on a timely basis. This represents useful experience and data for verifying and improving the factory fabrication equipment and procedures. This includes quality assurance and acceptance procedures.

### 3.2.2.8 Establish Component/Subsystem Test Facilities

Facilities will be required for carrying out the test program described in Paragraph 3.2.2.9. These represent conventional general purpose laboratory test facilities.

### 3.2.2.9 Carry Out Component/Subsystem Development Tests

Component and subsystem tests will be carried out to investigate and validate the design to the maximum extent practical prior to stage system testing. This testing includes the following elements:

## 3. 2. 2. 9. 1 Structural Tests. Six structural tests will be made, as follows:

Static Structural Tests. The ability of the structural design to withstand all critical load conditions without excessive deflection or failure will be confirmed. Full scale structural models of the L-I state, L-II stage, and adapter are to be subjected to distributed static loads representing all critical load conditions for handling, launch, and landing. Strains and deflections will be measured. Aerodynamic heating and base heating are to be simulated with infrared lamps.

Structural Resonance Survey. The vibration transmissibility characteristics of the structure will be determined. Full scale structural models of L-I stage and L-II stage, with mass-inertia models of suitably loaded tanks and all equipment items installed, will be subjected to sinusoidal vibration from 5 to 2000 cps in three directions at three input levels.

Mechanical GSE Tests. The ability of all mechanical GSE to support all expected loads without failure or impairment of function will be confirmed. At least one sample of each item of equipment is to be subjected to all critical loads. Critical deflections will be measured. Proof tests of every item will be conducted on equipment whose failure would be seriously damaging or injurious to personnel (such as hoist slings).

Functional Staging Test. The functional operation of separation systems will be verified. Mass models of vehicles to be separated will be connected by a flight configuration separation system. Each mass model is to be independently suspended to permit motion after separation. The separation sequence will be followed and the resultant motions observed.

Appendage Deployment Tests. Design of the various deployable spacecraft appendages will be verified. The various spacecraft appendages will be deployed from a simulated structure while the appropriate loading environment is duplicated. Measurements will be made of forces, acceleration, and deployment times. Development tests are to be made with engineering models. Final design verification tests will be made with flight configuration models.

Landing Stage Drop Tests. Design development information and structural design confirmation will be provided for the touchdown system. A full scale structural model of the landing stage is to be weighted to duplicate the inertia properties of an actual spacecraft. The specimen is to be dropped on surfaces of various textures at different combinations of horizontal and vertical velocity representing the extremes of expected landing conditions. The specimen will be instrumented with strain gages and accelerometers, and high speed movies will be made of each drop. These structural drop tests are to be conducted in

conjunction with functional tests of the landing system. The lunar gravity field is simulated by applying a 0.835 g upward force throughout the touchdown maneuver.

3. 2. 2. 9. 2 Separation Ordnance Tests. Design development information will be provided by separation ordnance tests. In addition, these tests will verify and qualify the final design and accept the production lot of ordnance. Separation ordnance is to be placed in a loading fixture simulating flight loads and is to be actuated. Firing time will be recorded. Development tests are to be made to size the charges and to provide preliminary current sensitivity data. Later design verification, qualification, and lot acceptance tests will all be made from a single production lot. The tests include:

<u>Current Sensitivity Tests</u>. Current sensitivity tests will be conducted for all-fire current and no-fire current by determining mean firing current and standard deviation around the mean (i.e., Bruceton method).

Qualification Tests. A large random sample will be tested after uniform environmental exposures. The purpose of these tests is to show freedom from workmanship defects, but the results can also be used as reliability demonstrations.

3.2.2.9.3 <u>Thermal Control Tests</u>. Four thermal control tests will be made:

Thermal Conductance Tests. The effective thermal conductivity of structural and insulating materials being considered in design will be measured.

Surface Properties Test. The absorptivity and emissivity of surface coatings being considered in design will be measured. The solar absorption and long wavelength emittance of proposed surface coatings will be measured. The degradation of these properties when

exposed to ultraviolet irradiation and micrometeorite impingement will be determined.

Electronic Equipment Thermal Control. The capability of the thermal control system to maintain electronic equipment within design temperature limits under realistic operating conditions will be verified. The operation and efficiency of the louvers will be tested in the cold-wall vacuum chamber. A model of the active fluid system is to be tested to gather data on reservoir insulation, valve operation, heat exchanger efficiency, tube sizing, and component compatibility.

Hot Firing Staging Test. The heating and pressure pulse during separation of L-II from L-I will be determined. A full-scale or subscale (depending on facilities) model of the L-I stage/L-II stage interstage structure is to be tested with the initial firing pulse of the L-II engines under low pressure environment. The heating and pressures in the interstage area will be measured.

### 3.2.2.9.4 Attitude Control Tests. Attitude control tests will include:

Component Functional Tests. Functional tests will be performed on an engineering model of each unit of the attitude control system.

These functional tests will be performed on the individual units under performance and environment conditions more severe than those expected in flight.

Control Loop Tests. Upon satisfactory completion of the individual component tests, the units will be assembled into a subsystem. The sensors and other units which do not interface with the attitude control electronics will interface with loads simulating the guidance and control computer. The reaction control electronics unit and the thrust vector control electronics will be operated in closed loop simulations to determine the adequacy of the subsystem design and to locate any interface problems which might have arisen. Also, tests will be performed to determine the effect of typical out-of-

tolerance conditions on system performance. From the results of these tests, specification limits and design margins will be established that will insure that subsystem and component acceptance tests provide sufficient assurance of adequate performance.

Gimbaling System Interface Test. The open loop transfer characteristics of the thrust vector attitude control system will be verified by test. A nonfiring engine and its gimbaling system will be utilized along with the attitude control electronics.

### 3.2.2.9.5 Guidance. Guidance elements to be tested are:

Design Development. Three levels of guidance design development testing will be accomplished: circuit or mechanism testing, individual subassembly testing, and subsystem level testing. In addition, tests on preprototype and prototype models will be conducted to ensure that the various assemblies are compatible with their ground support equipment.

Each assembly of the guidance subsystem will be subjected to design developmental tests that are pertinent to its functional requirements. After each assembly initially demonstrates compliance with its performance specifications, a subsystem integration test will be conducted. The purpose of this test will be to establish electrical and operational compatibility between the inertial measurement unit, the spacecraft computer, and the lunar approach sensors.

The early integration tests will be conducted prior to the formal vehicle integration tests and will not include simulation of physical interfaces. Preprototype and prototype models will be used. Subsequently, compatibility of the computer interfaces with the various assemblies will be established.

Design Verification. Functional tests will be performed on an engineering model of each unit of the guidance subsystem. Upon

satisfactory completion of these unit tests, the subassemblies will be assembled into a subsystem configuration with external stimuli simulated. Functional tests will be performed to determine the effect of out-of-tolerance conditions on a subsystem performance. In addition, a prototype model of the guidance subsystem will receive performance evaluation under flight conditions provided by airplane and/or helicopter flight tests. Of prime concern during these tests will be the performance of the TV camera and the guidance sensors (beacon tracker, altimeter, etc.). From the results of these tests, specification limits and design margins will be established that will insure that subsystem and component acceptance tests provide sufficient assurance of adequate performance.

Lunar Landing Simulation Program. A program will be required to simulate the TV/guidance/DSIF/Command Center loop. The objectives of this program will be to aid in the analysis and design of the TV system and to support the training of operating personnel for the launch operation. The program will establish design requirements for the TV system; evaluate the design of the landing site selection system, including procedures and man-in-the-loop considerations; provide design criteria for training simulators; and establish design requirements and alternate operating procedures associated with failure modes.

3.2.2.9.6 Electrical System. Functional tests will be performed on an engineering model of each unit of the electrical power subsystem. These functional tests will be performed on individual units under performance and environment conditions more severe than those expected in flight. Upon satisfactory completion of these tests, the units will be assembled into a subsystem. Subsystem tests will be performed on this configuration to determine the effect of typical out-of-tolerance conditions on system performance and to compare these results with those obtained during the design development phase of the program. From the results of these tests, specification limits

and design margins will be established that will insure that subsystem and component acceptance tests provide sufficient assurance of adequate performance.

Integration of the subassemblies comprising the electrical power subsystem will be accomplished during the design verification phase of the program. This integration will include electro-interference tests of units and of the subsystem. Interfaces between the electrical power subsystem and other spacecraft subsystems will be simulated, but adequate assurance of satisfactory subsystem performance will be provided only by actual inter-connection of subsystems. This will be accomplished prior to completion of the design verification test program.

3.2.2.9.7 Communications and Telemetry. Testing in this area will include:

Antenna Pattern Tests. The adequacy of antenna configuration and compatibility with DSIF requirements will be verified.

Functional Tests. Functional tests will be performed on an engineering model of each unit of the communications and telemetry subsystems. These functional tests will be performed on the individual units under performance and environment conditions more severe than those expected in flight. Upon satisfactory completion of these unit tests, the units will be assembled and tested as a subsystem.

DSIF/Communications Systems Test. An integration test encompassing the spacecraft communications system, the DSIF tracking stations, and the equipment located in the Space Flight Operations Facility (SFOF) will be conducted to ensure proper operation of all three elements. Actual (prototype) spacecraft communications and television systems will be used with appropriate test equipment.

The data transmitted from the spacecraft communications system includes telemetry, a coherent signal for tracking, and TV video derived from test patterns or a camera directed at terrain. Data received by the communications system includes the ground transmitter tracking signal, ranging code, and spacecraft commands. Comparisons will be made between the actual and the programmed responses of the equipment. These comparisons will indicate proper signal generation, polarites, bandwidths, and television picture quality.

Assessment of TV picture quality can be made more meaningful by attenuating the DSIF/spacecraft signals or by substituting a coax line in place of the air link and setting input power to the DSIF receiver to levels equivalent to those which would be obtained at lunar range.

After completion of the test, the spacecraft communications system should be checked out with the normal checkout set. This will establish compatibility between the tracking station and the communications system checkout set.

- 3.2.2.9.8 Ground Control Operations. Personnel must be trained in the procedures and functions associated with use of the Space Flight Operations Facility. This facility is assumed to be similar to that being prepared for the Surveyor program. The following training functions are required:
  - a) Handling and interpretation of tracking data
  - b) Generation and dissemination of trajectory and ephemeris data
  - c) Generation and checking of spacecraft commands
  - d) Use of the TV display for recognition of favorable landing areas during final descent
  - e) Control of the vehicle landing point during descent
  - f) Use of alternate procedures and operation of failure modes.

These training requirements are not extensive and it would appear that they can be performed in the actual SFOF without requiring a simulated facility specifically for training purposes. To permit the training operations to be performed, however, auxiliary equipment will be required to simulate spacecraft operations and functions.

These functions are:

- a) Command reception and verification
- b) Tracking
- c) Lunar landing site selections.

Training for the lunar landing site selection can be accomplished by use of a landing simulator located in a room adjacent to the SFOF. This simulator will include a gimbaled television camera, a lunar surface model, and an analog computer for simulation of guidance equations and vehicle dynamics. Actual components of the spacecraft systems will be used wherever practical. The display, controls, and equipment located in the control room will be the operational components.

3.2.2.9.9 Qualification Program. A production flight model of each component not previously qualified, or qualified as part of a subsystem, will be subjected to formal environmental qualification tests. The performance of the unit will be evaluated before and after exposure to the environmental limits specified. During the qualification tests, power and simulated input stimuli will be supplied as appropriate in order to evaluate the unit under operating conditions. The environmental qualification tests are expected to include thermal-vacuum, vibration, shock, humidity, acceleration, and possibly radiation. Electro-interference tests will be specified as part of the environmental qualification test program.

### 3.2.2.10 Develop L-I/L-II GSE Fabrication Capability

A task similar to Paragraph 3.2.2.4 is required to develop the capability for fabrication of module GSE.

### 3.2.2.11 Procure Support Equipment

Just as in Paragraph 3.2.2.6, it is expected that procurement rather than fabrication will be required to utilize to the maximum previously developed support equipment.

### 3.2.2.12 Provide L-I/L-II GSE

The module contractor will supply all GSE for the support functions described in Paragraph 3. 2. 2. 3. Non-deliverable prototype equipment will be used in component/subsystem testing to provide early test experience. Delivered units will be utilized at the assembly plant (Paragraph 3. 2. 4. 1), the stage static test facility (Paragraph 3. 2. 3. 5), the development flight test site (Paragraph 3. 2. 3. 9), and at the AMR launch complex.

### 3.2.2.13 Provide L-I/L-II Flight-Type Hardware

Flight-type hardware will be required for spacecraft system tests and operational articles. This will be provided by the stage contractor in keeping with the design responsibilities described in Paragraph 3.2.2.2.

### 3.2.2.14 Receive and Store L-I/L-II Hardware at Assembly Plant

An area at the assembly plant will be utilized by the stage contractor to receive and store stage equipment. This equipment will be utilized in stage assembly and in providing spares support at the assembly plant. Receiving inspection and limited testing will be accomplished at this area but all defective items will be returned to the stage contractor's plant for repair or disposition.

### 3.2.3 Tasks Associated With Spacecraft System Test

### 3.2.3.1 Establish Facility, GSE, Data for Factory System Test

A part of the assembly plant described in Al will be utilized for vertical mating of the L-I and L-II stages and will be outfitted with a complete complement of system operating and checkout GSE. The module contractor will be responsible for installing, checking out, and operating GSE associated with the module; however, the stage contractor will have the overall facility responsibility.

The capability for handling two spacecraft simultaneously will be provided by having two test bays designated as A and B. Bay A will be specially equipped for engineering development testing in addition to production system testing.

#### 3.2.3.2 Conduct System Integration Tests

The early verification of system functional compatibility and system procedures will be accomplished utilizing the EITV and Bay A of the System Test Facility established by Paragraph 3.2.3.1. In particular, the following will be done:

- a) Determination of electrical functional compatibility between subassemblies and subsystems
- b) Validation of mechanical GSE design and procedures (stage handling/mating, leak test equipment, mass properties determination, etc.)
- c) Verification of system test procedures (static firing, development flight test, launch operations)
- d) Verification of production system test procedures and validation of the process
- e) Validation of electrical GSE design, and familiarization of operating personnel with the final equipment configuration and operating procedures.

Following the above, the EITV will be utilized for the following continued testing:

- a) System electrointerference testing to demonstrate an adequate margin of safety between the maximum level of interference and the minimum level of susceptibility in the system.
- b) Verification of compatibility between the spacecraft and launch vehicle and the spacecraft and payload
- c) Investigation of functional and physical problems uncovered during assembly and acceptance process of EITV and subsequent spacecraft.

In all of the above production system test activities, the module contractor will be responsible for those tests directly associated with the module.

### 3.2.3.3 Conduct Production System Test

The purpose of the production system test program is to assure the customer that the spacecraft delivered from the factory is in working condition and is free from defects in workmanship. This assurance is provided by a series of tests progressing through subsystem, stage, and spacecraft.

The assembled and checked out L-I stage and L-II stage are first connected electrically for subsystem functional tests. Mechanical systems are actuated, deployed, or gimbaled within the required time spans as often as necessary to determine position and accuracy. None of these tests are life-cycle tests but they are repeated often enough to satisfy the operational requirements. The electrical subsystems are operated to evaluate performance. Voltages are varied for undervoltage and over-voltage control operation. In addition, the r-f systems are checked for signal reception and transmission. After the subsystem tests, stage acceptance tests are performed, with all subsystems being tested together. An operational sequence is tested in real time to determine possible areas of interference.

The stages are then mated and testing is continued on a space-craft level. A nose fairing and a dummy payload are installed and an engineering inspection of the complete spacecraft is made. The final spacecraft acceptance test is then performed. This test is similar to the stage acceptance tests, except that the stages are mechanically connected to form the complete spacecraft.

The final operations in the factory acceptance test program include a mass properties determination and a final propulsion system leak check. The program is ended with factory acceptance, which is the formal acceptance of the spacecraft from the factory. This acceptance is based on inspection records and test data obtained throughout the entire assembly and test process.

### 3. 2. 3. 4 Conduct Modified Production System Test

The first two development flight test spacecraft will utilize an L-II shell with a limited avionics installation as described in Paragraph 3.2.3.11. Hence, only the applicable elements of the full production system test will be required.

#### 3.2.3.5 Establish Facility, GSE, Data for System Static Test

A single two-position static firing facility is required with one position for L-I and the other for L-II. The basic facility design of each position is the same because stage geometry is similar and the propulsion module is the same for L-I and L-II. The model GSE will either be the same for each position or joint usage will be accomplished for such items as propellant and gas transfer. A single hardened control center will be utilized.

Test operations with an L-I and an L-II on two positions will be possible at the same time, although simultaneous or sequential firings are not required. It will be possible to install the L-II on top of an L-I in position and subsequently proceed to static test the latter.

Maintenance and test support facilities are required along with propellant storage and transfer, observation bunkers, remote camera positions, flame deflector cooling system, and unloading facilities.

Joint occupancy by the module contractor and the stage contractor will be required, with the module contractor having facility and GSE responsibility corresponding to the operating responsibilities described under the various assembly tasks. However, the stage contractor will have overall facility responsibility.

## 3.2.3.6 Conduct System Development Static Tests on L-II

Static tests on a flight prototype landing stage will provide the major part of final design verification and qualification type tests on the system and its subsystems under static firing conditions. During all of these tests, a failure reporting system and procedures for obtaining reliability assessment data will be strictly adhered to for system evaluation. The test series begins with delivery of the second flight prototype unit from the assembly plant, the EITV being the first assembled article. The system undergoes several full duration propulsion runs and exposes all subsystems to the environment of the static firing. Validation of preflight operations and procedures will be accomplished as well as validation of flight systems. Measurements typical to this type of test will be provided, including utilization of all flight instrumentation as appropriate to the static tests.

The module contractor will have an associate test conductor role. Thus, the module contractor will provide test personnel for module functional tests, propellant loading, servicing, checkout, operation, and evaluation for the static test program.

## 3.2.3.7 Conduct System Development Static Tests on L-I

In complement to the basic development static test program conducted with an L-II stage as described under Paragraph 3.2.3.6, some of the development static test objectives will be accomplished

with L-I stage firings. Recalling that essentially the same module is utilized in L-I as in L-II and that very little functional hardware is included in L-I, we see that only limited development static testing of L-I is required. Furthermore, the same module with the proper support structure would have been developed and verified at the module contractor's static test facility. Thus it is considered feasible to accomplish the L-I development static testing on DF1 and DF2, at the same time qualifying these articles for flight. Operation of all spacecraft equipment with an L-I firing and an L-II mounted on top of the L-I will be demonstrated. This will be accomplished with DF2 as the L-I stage and the captive test article as the L-II stage, to avoid delaying flight test of DF1.

### 3.2.3.8 Conduct Preflight Static Tests

This phase of the program serves the specific purpose of providing preflight static tests on each of the development flight test and operational launch spacecraft delivered as a part of the overall acceptance procedure. All of the spacecraft sent to the test site undergo a visual receiving inspection followed by an abbreviated spacecraft acceptance test. The spacecraft are then installed on the static test stand and are prepared for tests by installing and checking out GSE, instrumentation lines, and safety devices peculiar to static test stand operations.

Prior to a hot firing, the spacecraft are subjected to cold flow tests. In addition to verifying the cleanliness of the system, a thermal cycle is obtained, tank volumetric capacity is verified, and a space-craft facility compatibility is obtained. The hot firings consist of tanking all propellants and simulating the flight program as closely as possible. This flight simulation starts when ignition is obtained, and consists of ignition, main stage, gimbaling and throttling, and cutoff sequence.

At the conclusion of the static firing tests, the spacecraft are removed from the stands and cleaned. They are then prepared for transport to the refurbishing facility for system compatibility testing and final acceptance testing.

A representative series of tests to be performed on the flight article is given below.

L-I stage with L-II stage of top	Combined system compatibility check	No firing, all- systems test
L-I stage with L-II stage of top	Acceptance of L-I stage, environmental check of L-II stage	Full duration test of L-I and reaction control system with L-II stage on top. Engine control sig- nals generated through on-board equipment
L-I stage with L-II stage on top	Check separation L-II stage from L-I stage	Lift L-II stage off L-I stage after shutdown; verify separation
L-II stage, complete	Acceptance of L-II stage	Full duration test of L-II stage; en- gine control signals generated through on-board equipment

### 3.2.3.9 Establish Facilities, GSE, Data for Development Flight Test

A launch area similar to that described in Reference 3-1 will be required for the Little Joe II flight tests. It will include a hardstand to support the portable launcher supplied with Little Joe II, an underground instrumentation terminal room connected by landlines with the control center, a fire protection system, a gantry containing vehicle checkout equipment for installing and testing the spacecraft on the boost vehicle, and a hardstand for the portable propellant loading system. The hardstand must be protected from the launch environment

with a barricade. A control center will be needed for monitoring, launch, and post-launch instrumentation.

A support area containing a maintenance and checkout facility will be required. The maintenance and checkout facility, approximately 14,000 square feet, will have the capability of handling the complete spacecraft on the assembly stands. This facility is similar to the maintenance and checkout facility used at the captive test facility.

Joint occupancy by the module contractor and the stage contractor will be required, similar to the situation at the static test facility.

The module contractor will have facility and GSE responsibility corresponding to his module operating responsibility. The overall facility engineering task will be the stage contractor's responsibility.

### 3. 2. 3. 10 Checkout and Validate Development Flight Test Site

Following system integration testing (Paragraph 3. 2. 3. 2) the Engineering Integration Test Vehicle will be shipped to the Development Test Site where integration of the spacecraft and test site GSE will be accomplished. The spacecraft-GSE integration will precede receipt of the developmental flight test spacecraft at the test site and will accomplish the following:

- a) Verify adequacy of shipping and handling techniques and equipment
- b) Validate installation of checkout equipment at the test site.
- c) Verify launch control equipment design and validate installation of the equipment
- d) Familiarize on-site personnel with procedures and equipment required to handle, assemble-disassemble, perform system tests, and launch the developmental test spacecraft.

Thus, the EITV will undergo all handling and testing intended for developmental test spacecraft except for firing of the engines.

Following integration and validation testing at the Development Test Site, the spacecraft will be returned to the assembly, integration, and test facility, where it will be refurbished if necessary and subjected to spacecraft thermal vacuum tests.

### 3.2.3.11 Conduct Development Flight Test Program

3. 2. 3. 11. 1 General. The first Saturn V launch is planned for a lunar mission with a complete spacecraft and payload. To obtain a sufficiently high degree of confidence in these operational launches, it is necessary to conduct development flight tests on the spacecraft. A degree of confidence comparable to that expected from the Saturn V launch vehicle should exist for the spacecraft before the large expense of such a launch is warranted. Therefore, a development flight test program will be conducted utilizing the Little Joe II solid rocket booster developed by General Dynamics/Convair. The flight program will be conducted at the White Sands Missile Range.

The performance capability of Little Joe II limits the flight time available for the execution of spacecraft simulated lunar flight maneuvers. The flight time can be extended considerably, however, by operating the spacecraft engines with the spacecraft in a vertical nose-up attitude. By taking advantage of this fact and sequencing the flight phases to gain maximum flight duration rather than the closest sequence simulation, it is possible to simulate more of the lunar flight operations.

In addition to subjecting the spacecraft to the boost environment, the flight tests may accomplish the following flight operations:

- a) Separation of aerodynamic fairing from the spacecraft
- b) Separation of spacecraft froom boost vehicle
- c) Propulsion system operation for braking into lunar orbit
- d) Propulsion system ullage operation for midcourse maneuver and descent kick
- e) Separation of the L-II stage from the L-I stage

- f) Propulsion system operation for lunar approach braking
- g) Landing stage propulsion system operation, including translation and simulated landing maneuvers
- h) Perform guidance system functional tests during all modes of operation.

During each of these phases, all spacecraft subsystems can be functionally operated in the same general manner as they would operate during the lunar mission. For the terminal maneuver, simulated inputs of the guidance sensors will be required. In general, the flight modes can be conducted for a significant period of time compared with the expected lunar flight modes.

In conducting the above tests, the Little Joe II performance capability is not adequate for testing at full weight. It is necessary, therefore, to off-load part of the propellants or the payload. By off-loading 25,000 pounds of propellants it is possible to conduct flight phases as indicated above. Due to flight time limitations, it does not appear practical to simulate sun and star acquisition from an arbitrary initial attitude. It is possible, however, to conduct a vehicle reorientation of limited magnitude that would be adequate to check to reorientation capability and the final aspects of sensor acquisition. It is assumed that the Little Joe II boost vehicle will have been flight tested with a dummy spacecraft and the required fairing and adapter prior to the flights with spacecraft vehicles.

3.2.3.11.2 <u>Test Plan.</u> The flight test plan provides for five flights utilizing test articles DF 1 through 5. The first two flights (DF1, DF2) are to validate basic spacecraft flight worthiness and module operation under flight conditions. Some of the corresponding test objectives are as follows:

- a) Boost environment
- b) Spacecraft fairing separation
- c) Separation from launch vehicle
- d) Vehicle stabilization by reaction control system
- e) Propulsion system ullage mode operation
- f) Main engine start, steady operation, throttleability
- g) Propellant feed system operation
- h) Pressurization system operation
- i) Engine gimbaling
- j) Engine shutdown
- k) Instrumentation operation
- 1) Electrical power
- m) Range safety equipment operation.

The DF1, DF2 vehicles are made up of complete L-I stages with only a dummy upper stage. This latter utilizes an L-II structural shell to give the same external vehicle profile as for the complete space-craft. A simplified astrionics installation is included to provide attitude control, power, instrumentation, etc. The single stage approach is to prove out basic flight worthiness before risking the expensive upper stage. This also simplifies the initial tests so as to minimize test operations until proficiency has been gained.

The remaining three flights (DF3, DF4, DF5) are complete spacecraft. These flights will be conducted along the lines discussed in References 3-1 and 3-2.

Additional development flight testing by means of earth-orbital flight is discussed in Reference 3-2. This would probably require a Saturn IB and therefore represents a major added development cost.

Within the present discussion it is assumed that the necessary spacesoak data can be obtained from other programs, therefore earthorbital flights have not been included.

### 3. 2. 3. 12 Conduct Spacecraft Thermal Simulation Test

An earth-moon transit thermal simulation test will be conducted jointly by the module contractor and the stage contractor. A full-scale thermal model is to be tested in an  $LN_2$  cold wall vacuum chamber with surface heaters used to simulate external heat loads and engine firings. This test is to be performed with all heat dissipating equipment operating or simulated by heaters. The propellant tanks are filled with  $LH_2$  and  $LN_2$ , with the entire flight period being simulated.

Since solar simulation will not be available for a vehicle of this size, additional tests of scaled models in a LH<sub>2</sub> cold wall vacuum chamber with solar simulation are to be performed.

The L-II stage of the EITV article will be utilized for the full-scale test. Only the L-II stage is required, as essentially all equipment is represented in it and results are directly applicable to the L-I stage. The effect of the L-I stage must be simulated, however, to achieve a realistic environment for the L-II stage. A vacuum chamber facility of appropriate size will be required along with associated LH<sub>2</sub> and LN<sub>2</sub> storage and handling facilities and LH<sub>2</sub> and LN<sub>2</sub> vent capability. A scaled thermal model will also be required for the companion tests.

### 3. 2. 3. 13 Modify Factory System Test Facility

The factory system test facility will be updated to incorporate any modifications that have been developed as described in Paragraph 3.2.4.12.

### 3. 2. 3. 14 Conduct Additional Integration Tests

The EITV, after incorporation of any modifications as described in Paragraph 3.2.4.12, will be installed in the modified factory system

test facility. Additional integration tests will be conducted as required, to validate these modifications and to investigate any outstanding development problems.

### 3.2.3.15 Modify Static Test Facility

The static test facility will be updated to incorporate any modifications that have been developed as described in Paragraph 3.2.4.12.

### 3. 2. 3. 16 Conduct Additional System Development Static Tests

The captive L-II stage, after incorporation of any modifications as described in Paragraph 3. 2. 4. 12, will be installed at the modified static test facility. Additional static tests will be conducted as required, to validate these modifications and to investigate any outstanding development problems.

### 3.2.3.17 Establish Facilities, GSE, Data for AMR Launches

Launch operations will be performed at the Atlantic Missile Range (AMR). The AMR facilities will consist of the launch area for the vehicle (Complex 39), vertical assembly facilities, spacecraft checkout and modification facility, ordnance storage facilities, and engineering support facilities.

A spacecraft checkout facility approximately 25,000 feet square will be required. This facility will have provisions for the mating and checkout of two spacecraft plus subsystem checkout capability. Work on spacecraft and landing stages will be performed on the assembly fixtures. This part of the facility will be approximately 100 feet wide, 160 feet long, and 60 feet high, with a 30-ton bridge crane. A low bay portion of approximately 9,000 square feet will be required for engineering support.

Responsibilities in establishing the spacecraft launch capability will be divided between the stage contractor and module contractor in accordance with their respective design and operating responsibilities.

# 3.2.3.18 Conduct Tests/Checkout of AMR Launch Capability

The EITV article will be utilized to verify the AMR launch capability in a manner similar to that described in Paragraph 3. 2. 3. 9 relative to the development flight test site checkout.

## 3.2.3.19 Conduct Operational Flights

The first flight at AMR will be an operational lunar mission with a complete spacecraft and payload.

The major launch operations to be accomplished are as follows:

- a) Assembly and checkout operations on spacecraft
- b) Interface tests with booster and payload
- c) Final mating operations
- d) Final launch preparations
- e) Participation in countdown operations
- f) Evaluation and reporting of launch site operation data
- g) Planning, scheduling, and control of spacecraft launch operation
- h) Coordination with NASA and AMR
- i) Preparation of support documentation.

Receiving inspection and complete servicing, checkout, and acceptance are essentially the same as the factory functional and acceptance process. These are performed in the AMR hangar or checkout facility.

The spacecraft is assembled to the composite launch vehicle in the Vertical Assembly Building and is checked for mechanical fit and alignment, electrical compatibility, and interface matching. Compatibility with the control equipment is also established. The flight payload and nose fairing are sequentially installed, and

appropriate interface matching is assured. With the payload and nose fairing assembled, compatibility of the spacecraft and payload is established followed by a compatibility check of the total space vehicle. After these operations, the nose fairing and payload are removed from the system and the vehicle is moved to the ordnance station for installation of all flight ordnance devices. The vehicle is moved to the launch site at this point in the operational sequence, and a launch control facilities compatibility check is made with the composite space vehicle and spacecraft.

The final functional performance check is conducted next. This is remotely controlled and monitored from the blockhouse, and includes an exercise of all command modes and operational events, including a mock countdown of the composite system (launch vehicle and spacecraft). The payload and nose fairing are then installed and flight readiness is demonstrated. At the conclusion of the flight readiness demonstration, final launch preparations are initiated and the sequence culminates in launch.

The above spacecraft launch operations will be performed jointly by the stage contractor and the module contractor. Division of responsibility will be in accordance with the respective design responsibilities.

# 3.2.4 Tasks Associated With Spacecraft Assembly

# 3. 2. 4. 1 Establish Facility, GSE, Data for Assembly

Normally, it would be desirable for the assembly facilities to be located next to the major fabrication facility. The size of the completed spacecraft, however, will require that the assembly plant be located near suitable transportation. Accordingly, it is assumed that the assembly plant will be located at some distance from the parts production plant.

The assembly plant requires facilities for:

- a) Receiving
- b) Incoming inspection
- c) Functional testing
- d) Stage assembly
- e) Stage testing
- f) Refurbishment of spacecraft after captive tests
- g) Shops and supporting functions
- h) Shipping and storage.

Transportation for large subassemblies, such as structural sections and tankage, will be required. Shop areas will be needed for machining, metal working, welding, bonding, plating, cleaning facilities, X-ray, inspection, instrumentation calibration, and bench maintenance. A complete propulsion cleaning facility is required, including space and equipment for cleaning tankage and plumbing. There will be special requirements for environmental control and large power requirements in the final assembly, integration, and system checkout areas.

Joint occupancy by the module contractor and the stage contractor will be required, with the module contractor having facility and GSE responsibility corresponding to the operating responsibilities described under the various assembly tasks. However, the overall facility engineering task will be the stage contractor's responsibility.

# 3. 2. 4. 2 Integration and Assembly of the Engineering Integration Test Vehicle (EITV)

The initial integration and assembly of the EITV as a complete system utilizing flight type hardware is part of the engineering integration test program. It will serve to verify the integration and

assembly process. In particular, the following will be accomplished:

- a) Validation of tooling and mechanical GSE design along with the associated handling and assembly procedures
- b) Determination of physical compatibility between constituent units and subassemblies in the vehicle
- c) Verification of procedures for interface evaluation tests performed progressively as the vehicle is assembled.

The assembly process is carried out jointly by the stage contractor and the module contractor, with each having well defined tasks appropriate to their respective design responsibilities. Thus the stage contractor physically installs the module tanks while the module contractor is responsible for all plumbing assembly that affects system cleanliness or leakage control.

3. 2. 4. 2. 1 Install and Checkout Module in L-I for EITV. The basic structure and all module assemblies required for the L-I stage are delivered from the finished hardware store area. Immediately following receipt of the hardware, a functional or physical inspection is performed. This operation ensures that all items are the correct configuration and have been acceptance tested. Following the inspection, a systematic and progressive assembly is undertaken. Assembly of module components must be conducted in an environmentally controlled area. Flight weight structures of this size are not dimensionally stable if the surrounding environment is allowed to temperature cycle. This method of operation allows expedient and reliable assembly and is compatible with the program schedule.

The two  ${\rm LO_2}$  and two  ${\rm LH_2}$  tanks are mechanically mounted to the corresponding stage support structures by the stage contractor. The stage contractor similarly mounts the two RL10A engines to their thrust structures. The remaining propulsion assembly operations are then accomplished by the module contractor.

All propellant and pneumatic systems are leak tested after assembly and before the next operation starts. The leak test is a low pressure test for major discrepancies. High pressure leak tests and calibrations are performed later. It would be possible to conduct all assembly operations and then to perform a leak check. However, this would entail extensive rework if a deficiency were noted.

The electrical harness for the module is installed and its separate umbilical is connected to the module checkout GSE by the module contractor, who also conducts the module functional tests. The thrust vector control gimbal system installation is tested to ensure that all alignments and responses are within tolerances. These operations are performed with test console stimuli and the spacecraft cabling.

Prior to the propulsion system purge and calibration, a test of real time response and correlation verifies sequencing of all items in the propulsion system, using test console stimuli and spacecraft propulsion system responses. After this test, the L-I stage is prepared for the propulsion system calibration and purge. This consists of flushing all tanks and lines with an inert liquid in order to clean the system and preserve it. In addition, all system orifices are checked for proper sizing, a volumetric measurement of the propellant tanks is obtained, the level switches are set, and the propellant utilization subsystem plumbing is validated.

It is not feasible to conduct an all-systems test on the L-I stage as an end item because a majority of the stage stimuli are generated in the landing stage, but the stimuli generated by the test console serve the same purpose at this point.

3. 2. 4. 2. 2 Install and Checkout Stage Equipment in L-I for EITV. Very little equipment that is not part of the module is required in L-I. This stage equipment (instrumentation, cabling, separation mechanisms) is

installed and checked by the stage contractor. After all equipment has been installed and verified, the L-I stage is ready for transport to the area of spacecraft assembly and system test.

- 3. 2. 4. 2. 3 Install and Checkout Module in L-II for EITV. This task is essentially the same as for Paragraph 3. 2. 4. 2. 1.
- 3.2.4.2.4 Install and Checkout Stage Equipment in L-II for EITV. This task includes installation and checkout of the spacecraft astrionics equipment for attitude control, guidance, communication and telemetry, power, range safety, flight sequence control, etc. It also includes mechanical equipment such as separation mechanism, thermal control, landing gear, deployable mechanisms, etc. This equipment is the responsibility of the stage contractor.

After all subsystems are installed and checked, several tests will be performed with the landing stage system, using a test set to simulate L-I stage functions. These tests include an r-f systems test, functional tests of subsystems, and a systems integration test. These tests will include evaluation of computer performance by the solution of sample problems, servo loop response tests, end-to-end communication subsystem tests using the r-f link, evaluation of the television transmission capability, and determination of the electric power generation and distribution characteristics. Test data will be accumulated by hard lines and by telemetry (r-f link), and will be processed by the electrical GSE. Thus, these final tests may be considered as a dry run of the first phase of spacecraft acceptance testing and a demonstration that assembly operations have been successfully completed.

# 3.2.4.3 Install and Checkout Module in L-I

This task is the production equivalent of Paragraph 3. 2. 4. 2. 1 and is applicable to DF1-5, No. 1-4. Special R and D instrumentation will be installed as required.

## 3.2.4.4 Install and Checkout Stage Equipment in L-I

This task is the production equivalent of Paragraph 3. 2. 4. 2. 2 and is applicable to DF1-5, No. 1-4. Special R and D instrumentation will be installed as required.

## 3.2.4.5 Install and Checkout Module in L-II

This task is the production equivalent of Paragraph 3.2.4.2.3 and is applicable to Captive L-II, DF3-5, No. 1-4. Special R and D instrumentation will be installed as required.

## 3. 2. 4. 6 Install and Checkout Stage Equipment in L-II

This task is the production equivalent of Paragraph 3. 2. 4. 2. 4 and is applicable to Captive L-II, DF3-5, No. 1-4. Special R and D instrumentation will be installed as required.

#### 3. 2. 4. 7 Install and Checkout Equipment in L-II Shell

A special L-II stage without a module will be utilized for the first two development flights (DF1, 2) as described under Paragraph 3. 2. 3. 11. The required simplified attitude control system, electrical power, instrumentation, etc., to support flight test of the complete L-I stage will be required. This task represents a modified and very simple version of Paragraph 3. 2. 4. 6.

#### 3. 2. 4. 8 Refurbish and Checkout System

It is assumed that refurbishing of the spacecraft after a static firing will be done at the assembly plant, where facilities for all repairs and refurbishing are available. The spacecraft stages are separated, installed on work dollies, and sent through the refurbishing operations. In normal practice, this operation would consist of replacing items where necessary after the spacecraft has been subjected to static tests, and would not result in major subsystem replacement. The stages then undergo subsystem functional tests and are assembled for a repeat of the spacecraft acceptance test. This is followed by a final leak check and a refurbish acceptance procedure. The latter is a formal acceptance based on complete inspection records and test data from factory acceptance, and from the interim operation through static test and refurbishing operations.

As a final operation, the spacecraft is prepared and shipped to the appropriate sites for development tests or launch operations.

# 3.2.4.9 Modify, Refurbish and Checkout Spacecraft

As a result of system integration testing, static testing, and development flight testing it is to be expected that various spacecraft and support system modifications will be developed. These will be incorporated in the flight vehicles and GSE on a timely basis to allow validation prior to the first operational flight. Final validation will probably be accomplished concurrently with incorporation in operational vehicles. In general these modifications will be incorporated in the EITV article and in the captive L-II article for validation in the additional test activity covered by Paragraphs 3. 2. 3. 13 and 3. 2. 3. 15.

#### 3.3 MODULE PROGRAM

In the program described in Section 3.2, the basic module development work was separately identified and a module contractor was established for carrying out the various tasks. Such a separation suggests the possibility of actually proceeding initially with only a module development program and establishing the associated stage development work later. This would allow the important module development to proceed without a total program commitment or funding.

The module development would include all the tasks covered by Figure 3-3 and Paragraph 3.2.1. Thus, flight type module hardware would be assembled into a module test article and static testing would be accomplished. This would include the demonstration of module support equipment suitable for the spacecraft development program as well as operational launches. Equipment would be qualified for the expected spaceflight environment.

For such an approach to be possible it is necessary to supply a framework of design and program requirements. Without such a framework the module development could not be established. Furthermore, for the module development to lead to a well conceived system design that is truly suitable for the wide variety of mission applications contemplated, these underlying requirements must take into account the significant characteristics of all such missions. The associated work must be carried far enough to insure a true multi-application design. For example, in order to take full advantage of the module concept it is imperative that the propellant feed system hardware and geometry remain the same. Otherwise much additional testing would be necessary for each application. These considerations imply that a large amount of system analysis, engineering, and integration work would be required outside the module contractor task as defined in Section 3.2 for the logistic vehicle development alone.

In addition to basic design requirements it would be necessary to establish detail integration data pertinent to all the module contractor equipment. This would apply to equipment associated with factory assembly, system test, and launch operations, as well as flight equipment. A considerable amount of work in the module development program would be invested in design of such equipment, and an important program aspect is the actual operating experience to be gained with this equipment during the program. If this equipment were not suitable for the subsequent spacecraft programs, a major part of the module development effort would be wasted. Of course, to develop the data required to achieve this applicability implies a major "software" effort.

The implication of the above discussion is that an effective development program for the module alone should be undertaken only within the framework of essentially the same system engineering effort as if the total MMM spacecraft program were being implemented. The relatively low cost of such software effort as compared to a spacecraft hardware development would still allow the program to get underway without a major program funding commitment.

# 3.4 TAILORED LOGISTIC SPACECRAFT PROGRAM

In order to examine the development program implications of the modular approach it is necessary to consider a representative tailored version of the lunar logistic spacecraft and compare the two development programs. In keeping with the present work statement, the LLS program presented in Reference 3-1 will be considered to be the tailored version. A description of this spacecraft is given in Volume II, Section 4. Some information in regard to the associated development program is given below with details available in Reference 3-1. In general, the basic elements correspond closely to those of the modular program discussed in Section 3.2.

The program for the tailored lunar logistic spacecraft has been based on the following ground rules:

- a) Forty-nine months to first operational launch
- b) First operational mission planned for lunar landing with full payload
- c) Final drawing release for structural subsystems, 15 months; for critical subsystems, 18 months
- d) Fabrication start for first complete vehicle, 16 months
- e) Fabrication requires 6 months
- f) Assembly requires 7 months
- g) Acceptance plus transport, 1-1/2 months
- h) Preflight static firing, 1-1/2 months
- i) Final acceptance, 1-1/2 months.

Test hardware for development tests, subsystem design verification tests, initiation of integration tests, and battleship tests becomes available early in order to support these programs, as shown in the schedule of Figure 3-6. The first complete spacecraft which can be used for systems testing is available from the assembly line 26 months after contract start. The fabrication and assembly times used are estimated as typical for a contractor to do a reliable job on a vehicle of this complexity. The production rate of about one spacecraft a month is required to support the program leading to the 49-month launch date.

The test program includes battleship tests starting at the end of the 13th month, utilizing a prototype propulsion system, heavy tanks, and plumbing. In the 22nd month, the battleship test is updated to include prototype equipment and thus provides static tests on flight type hardware. This, together with the static tests on the first prototype spacecraft beginning in the 28th month, provides approximately 21 stand-months of testing experience prior to the first Little Joe II development flight. Static firing testing of the flight equipment is also started early enough to feed back changes to the development flight spacecraft. The static

firing experience is still limited, however, prior to initiation of preflight static acceptance tests. The engineering integration tests also will provide only limited support to the static test site and change feedback for the development flight articles. Both of these factors are a result of early production limitations.

The development flight test program starts in the 34th month and continues through the next 7 months, with all tests completed before final assembly of the first operational launch spacecraft. The flight rate is somewhat optimistic as necessary changes between development flights may cause slips in the schedule. Changes resulting from the development flights can be incorporated in the operational spacecraft during their assembly process.

Six development flights are planned, three with complete spacecraft and three with partial spacecraft, making a total of five deboost stage flights and four landing stage flights. This represents the elimination of one partial spacecraft flight from the program in Reference 3-1. The revision was made in order to put the modular and tailored programs on the same basis and achieve a more equitable comparison.

In comparing the tailored spacecraft program with the modular one of Section 3. 2, the central point of difference lies in the fact that the modular program requires the development of only one propulsion system for the two stages, whereas the tailored spacecraft program requires the development of two different propulsion systems. This has a definite effect in the corresponding design and analysis of the flight equipment of the GSE, development of fabrication capability (tool design, tool requirements, personnel training), component/subsystem testing, the amount of test hardware required, component/subsystem test facilities, qualification testing, propulsion development static testing, static test facility requirements, GSE requirements, system test procedures. personnel training, etc. The fact that propulsion represents a significant

part of vehicle development means that such a difference is not unimportant. To make such differences quantitative requires actual cost data. Specific figures and further discussion of this comparison of the two programs is therefore relegated to Section 4.

# 3.5 MODULAR PAIR, LOGISTICS AND MANNED SPACECRAFT PROGRAM

Development plans for modular and tailored logistic spacecraft have been discussed in the preceding sections. It now remains to extend these into corresponding development plans for modular and tailored lunar direct flight pairs as called for in the study work statement.

A comparison of the modular versus the tailored stage concept is made possible by application of the same ground rules and assumptions to the formulation of the pair program plans. The plans have been outlined in the form of schedules identifying the significant program characteristics. Conventional, well understood aspects common to most programs have been de-emphasized for clarity. This section introduces the pair program plan ground rules and describes the modular pair program. Section 3.6 examines the equivalent tailored pair program and briefly compares the modular with the tailored approach.

# 3.5.1 Assumptions and Ground Rules

The same basic assumptions that were used in the LLS Study Development Plan of Reference 3-1 have been re-applied to both the modular and tailored pairs. These are listed in Section 3.2 of this report. The following ground rules have been applied in outlining the two programs:

- a) The flight test programs for both approaches have the same basic objectives, thus providing a common base for preparation of and comparison of the two development programs
- b) Development of all subsystems is carried out concurrently, with developed hardware available when required

- c) Any increase in facilities over those required for the logistic vehicle development is held to a minimum
- d) The use of facilities for logistic and for manned vehicle operations are combined wherever practical
- e) The stages are treated as individual units to identify corresponding operations to the same level of detail in both programs (see Paragraph 3.5.3).

## 3.5.2 Baseline Flight Test Program

Drawing from Reference 3-1 and Volume VII of Reference 3-2, the generally accepted constraint relative to cost and availability of the Saturn V dictates the use of alternate boost vehicles wherever possible. Therefore a study was made of flight objectives achievement versus type of flight. The type of flights considered included the use of Little Joe II lob-shots and Saturn IB orbital flights in lieu of Saturn V earth-lunar flights.

The basic flight objectives are listed in Table 3-1 against space-craft configuration and the types of flight. Satisfaction of flight objective under completely realistic conditions is indicated for each combination by an X. It is to be noted that only the earth to lunar surface and return flight satisfies all objectives. Special landing vehicle piloting and return vehicle takeoff tests would be required to supplement the flight modes shown.

From these data, development flight test programs were outlined for each configuration in which all objectives were met and the number of flights to achieve milestone data was consistent between configurations. A summary of these test programs is shown in Table 3-2. The flight tests established for a particular vehicle such as the modular manned, are shown in vertical columns under the appropriate heading. The general stage configuration of the flight is indicated by the key along the flight number line. The major flight objectives for each flight are identified at the end of the line. Blanks indicate a lack of test

\* Table 3-1. Types of Flight Test Versus Accomplishment of Objectives

	LLS	S, t		LLS			1			MM	MMM Study	udy				٠	
	STL Reference	L ence	Rei	NASA Reference	Se			Ĭ	Modular	LT.			T	Tailored	pə.		
	Logistic	stic	긻	Logistic	J	깈	Logistic	اً	Ma	Manned		Log	Logistic		Ma	Manned	
Basic Flight Objectives	Lob	Lunar	Гор	tidTO	Lunar	Top	tidrO	Lunar	Гор	1id±0	Lunar	Lob	1id±O	Lunar	Гор	tidxO	Lunar
Structural Integrity	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Landing Gear Performance		×	0	0	×	0	0	×	0	0	×	0	0	×	0	0	×
Astrionics Performance	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Propulsion Performance	×	×	<b>×</b>	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Separation in Flight	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Hover	×	×	×	0	×	×	0	×	×	0	×	×	0	×	×	0	×
Space Soak (life test)	0	×	0	×	×	0	×	×	0	×	×	0	×	×	0	×	×
Manual Piloting	t	ı	ı	t	ı	1	ı	ſ	0	0	×	ı	1	1	0	0	×
Landing Impact	0	×	0	0	×	0	0	×	0	0	×	0	0	×	0	0	×
Lunar Takeoff		ı		ı	i	ı	ı	ı	0	0	×	t	ı	ı	0	0	×

\*X indicates that objective is met under completely realistic conditions; 0 otherwise. - indicates not applicable.

Table 3-2. Summary of Flight Test Program

CONFIGURATION												TAS	101	-							Т	KEY:				
]			_			MO	DU	LAR				П				LO	REC	>				L = LIVE STAGE D = DUMMY STAGE				
		L	OG	IST	ICS	L	_^	140	NNE	D			LOC	SIST	ICS	_	W	N	NE	D	4	SD= SEMI-LIVE I.E.,				
TYPE OF FLIGHT			L-1 STAGE L-11 STAGE GUIDANCE		L-I STAGE	L-H STAGE	L-III STAGE	GUIDANCE	APOLLO	MAN		L-I STAGE	L-11 STAGE	GUIDANCE	L-I STAGE	L-11 STAGE	SUN ACTUA	15000	Arouro	MAN	INCOMPLETE MAN SUPPORT EQUIP.ETC. Y = YES N = NO FLIGHT OBJECTIVES					
			L	D		Ĺ	D	D	Z	D	Z			D	z	l	D	,	7	D		VERIFY TEST FACILITIES SEPARATE DEBOOST STAGE DEBOOST ENGINE PERFORMANCE FLIGHT DYNAMICS				
LOB-SHOT, LITTLE JOE II, WSMR		2	L	D	z	ı	D	0	Z	D	Z		   	D	z	L	C	'	7	D	Z	VERIFY DEBOOST PNGINE PERFORMANCE VERIFY SEPARATION - ATTITUDE CONTROL - FLIGHT DYNAMICS				
		3	L	L	٧			.   0	) N	D	2		D	L	Y	C			Y	D	2	LANDING STAGE ENGINE PERFORM- ANCE SEPARATE LANDING STAGE VERIFY -ATTITUDE CONTROL AND GUIDANCE -FLIGHT DYNAMICS				
-SHOT, LITI		4	   L 	L	\ \ \			.	.   ٧	Si	И		    L	L	٧		. ,	-	Y	SD	7	SEPARATE ALL STAGES DEMONSTRATE GUIDANCE/CONTROL ENGINE PERFORMANCE-ALL STAGES				
ğ		5	L	ί	V				,	, sı	Z				Y		. .		۷ _	SD	Z	SAME AS ABOVE TO PROVIDE FURTHER DATA AND VERIFY CONDITION OF RETURN STAGE OR EQUIVALENT AT COMPLETION OF SEQUENCE				
		6	6										     		·							SAME AS 4 AND 5 TO PROVIDE FURTHER DATA . (SAME AS 5 ON MODULAR CONCEPT)				
TAL- - 18, AMR		7	7 USEFUL			1				1		1		TTLE R N				L	Υ	L	Z	VERIFY FULL SCALE SEPARATION FROM S IV -DEMONSTRATE FULL SEQUENCE IN SPACE ENVIRONMENT. LIFE TEST. DEMONSTRATE RETURN AT END OF SOAK VERIFY APOLLO FUNCTIONS				
ORBITAL- SATURN C-18, AMR		8			\ \	<b>利</b> <b>7</b>	L	L		٧	L			CHA		7	į	L	Y	ı	Y	SAME AS 7 PLUS MANNED APOLLO				
		9	١	-		Y	L	L		<b>Y</b>	۱				L	Y	L	L	Y	l	. Y	LUNAR LANDING WITH USABLE CARGO				
IN C-5, AMR		10	1,	.   1		۲	L	١	-	Y	۱ ,	1			L	Y	L	Ĺ	Y	l		LUNAR LANDING WITH USABLE CARGO				
LUNAR, SATURN C-5, AMR		11	+	-	-	Y	L	L	L	Y	L	<b>Y</b>			L	Y	L	L	Y		١,	LUNAR LANDING WITH USABLE CARGO				
	•	12	+			Υ	L	L	L	Y	L	   			ı	Y	l	L	Y			LUNAR LANDING WITH USABLE CARGO				

NOTE:
(MODULAR AND TAILORED PAIRS WITHIN DOTTED LINES)

requirement for the corresponding vehicle. The combined flight tests applicable to the modular pair and the tailored pair are contained within the dashed lines under the appropriate heading. The flight test programs provide a base for preparation of consistent development programs.

Both programs achieve the milestone data on roughly the same number of flights. The modular logistics vehicle requires one less flight than the tailored vehicle because the modular version has only one type of propulsion compared with two for the tailored system. In combination, the modular manned and logistics vehicles can share development of the L-I and L-II stages thus eliminating three initial flights as compared with separate development of the modular manned vehicle. Another advantage is realized by the combined modular pair test program in that data from orbital manned vehicle flights can be applied to the logistics vehicle. Integrating the tailored pair development programs yields no advantage over development of each vehicle independently.

# 3.5.3 Combined Stage Assembly and Checkout

The manner in which the stage assembly and checkout operations are combined on the modular pair and the tailored pair is summarized in Figure 3-7, showing the unit flow of major hardware from component procurement through launch operations. The main difference between the two concepts is that the modular pair shares the same module contractor and stage contractor (hence, corresponding operations and facilities), while the tailored pair, having little or no common hardware, have separate contractors (hence, operations and facilities) for the logistics and manned vehicles.

Figure 3-7 also serves to identify the operations shown on the program schedules in Paragraphs 3. 5. 4 and 3. 6. 1 where the operations are shown in their proper parallel and sequential positions for the entire series of hardware. The schedule presentation in this manner

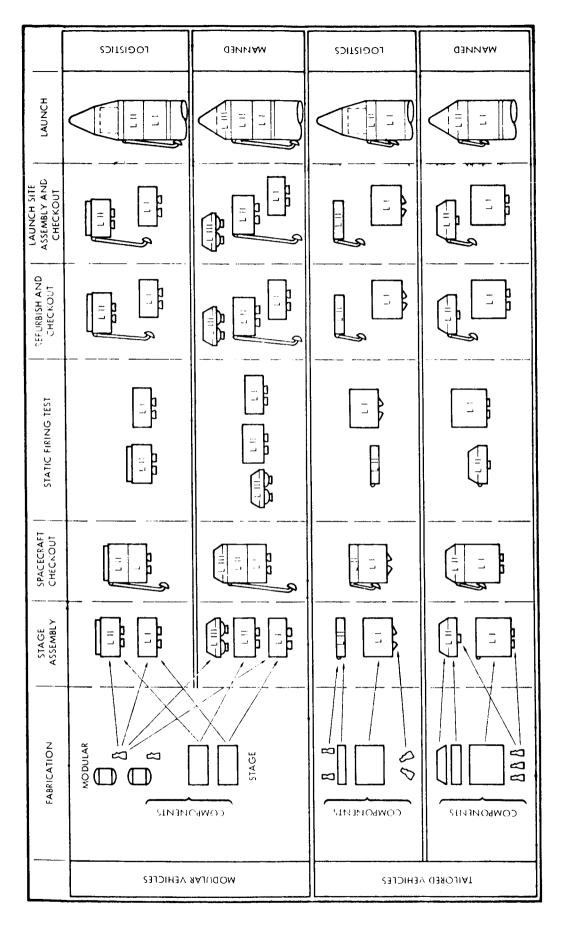


Figure 3-7. Unit Flow of Major Hardware

allows an indication of the number of operation stations or facilities required to support the program for a specific schedule.

# 3.5.4 Modular Pair Program Plan Outline and Schedule

The combined program plan for the logistics and manned modular lunar spacecraft is summarized in schedule form in Figure 3-8. The program plan for the pair is derived from that of the logistics vehicle described in detail in Section 3.2. The information in that section is not repeated here and should be considered as generally applicable to the pair program. Such tasks as program management, system engineering, design and analysis, etc., are similar on all programs of this nature. Difference within these conventional tasks, from program to program, occur due to changes in complexity or parts count. These differences show up as cost differences. No change in elapsed time to accomplishment is anticipated. Therefore, the first three headings on the program schedule are identical to those of the logistics vehicle in both meaning and schedule.

The fabrication and assembly tasks show significant differences from the individual vehicle program. By combining the manned vehicle program tasks with those of the logistics vehicle more effective use of the facilities is realized. For example, the stage assembly station requirements increase by 60 percent rather than 100 percent and less saturated stations such as the high bay systems test and offsite static tests do not increase at all. The elapsed time on station for each article is shown in Figure 3-8 as a block with article number on a single line (the station). Subsequent articles follow. The down time for changeover is included within the article block. The time the station is not utilized (or adjustment time) is shown as blank space. It should be noted that further advantage of the facilities could be realized with different ground rules or different choice of tasks on a particular station. Development and qualification testing is similar in time to the logistics vehicle program.

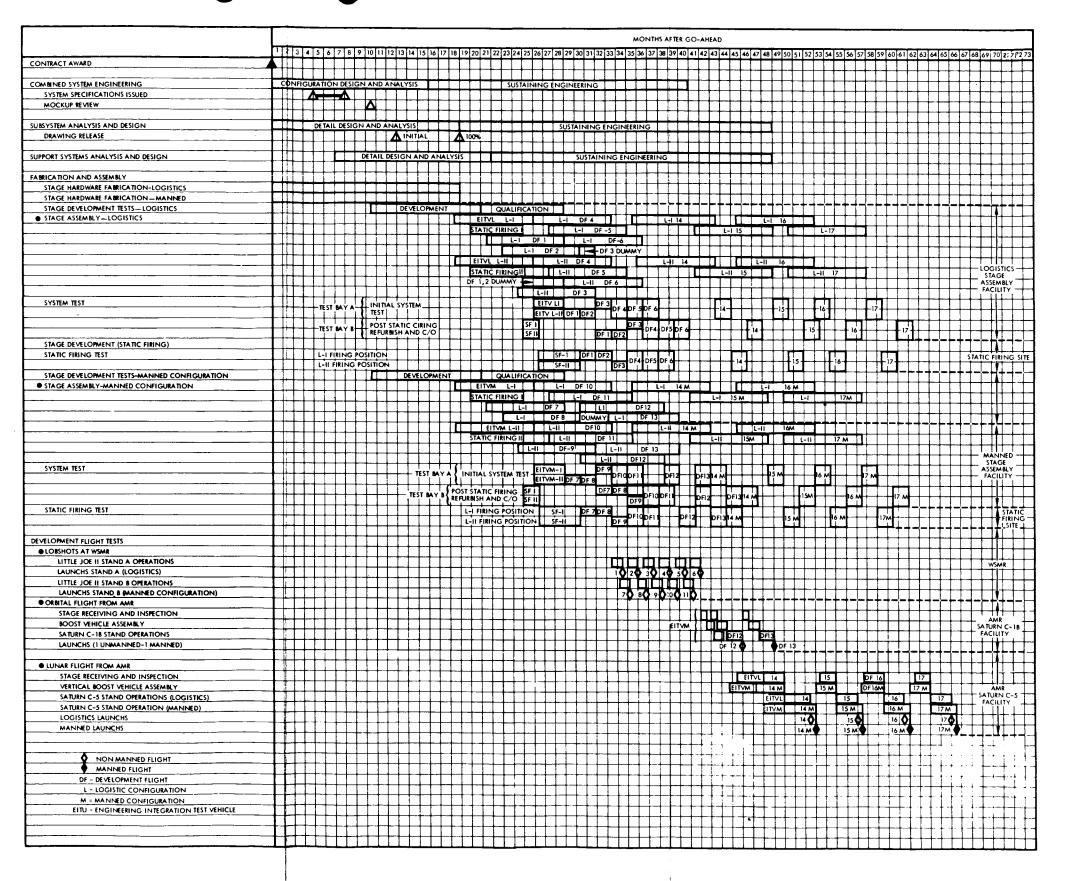


Figure 3-8. Program Schedule for Combined Logistic and Manned Modular Lunar Spacecraft

The rate of lob-shot launching in development flight test remains the same as the individual program; however, an advantage in time between launches of similar configurations (more data analysis and fix time) is realized by alternate launches of logistics and manned test vehicles. The rate of test flights of the modular components stays the same as the overall launch rate.

Preparation for the orbital test flight is concurrent with the final lob shots, and can be moved forward in time by 2 months if lob shot flight results so indicate. The choice of time between the initial unmanned orbital flight and the final manned one is arbitrary at 4 months. This could be reduced to 2 months if desired.

The interval in time from final orbital launch and first lunar launch is also arbitrary and could be moved up 2-1/2 months if desired. Time between launches is selected as 4 months but could be reduced to 2-1/2 months.

# 3.6 TAILORED PAIR, LOGISTICS AND MANNED SPACECRAFT PROGRAM

The formulation of the combined development plan for the logistics and manned lunar spacecraft follows the same ground rules as for the modular pair. The main headings for the program tasks are the same and the schedule is nearly the same. The LLS Study provided the basic information in regard to the tailored logistic vehicle; the tailored manned vehicle program was superimposed upon this.

# 3.6.1 Tailored Pair Program Plan Outline and Schedule

Figure 3-9 summarizes the combined development plan for the tailored pair. The format is identical to that used for the modular pair so that comparisons of the same areas can be made. The program plan and schedule presented in detail in Reference 3-1 were taken as the tailored logistics vehicle plan for this study. The information presented is directly applicable to the tailored pair program in that the

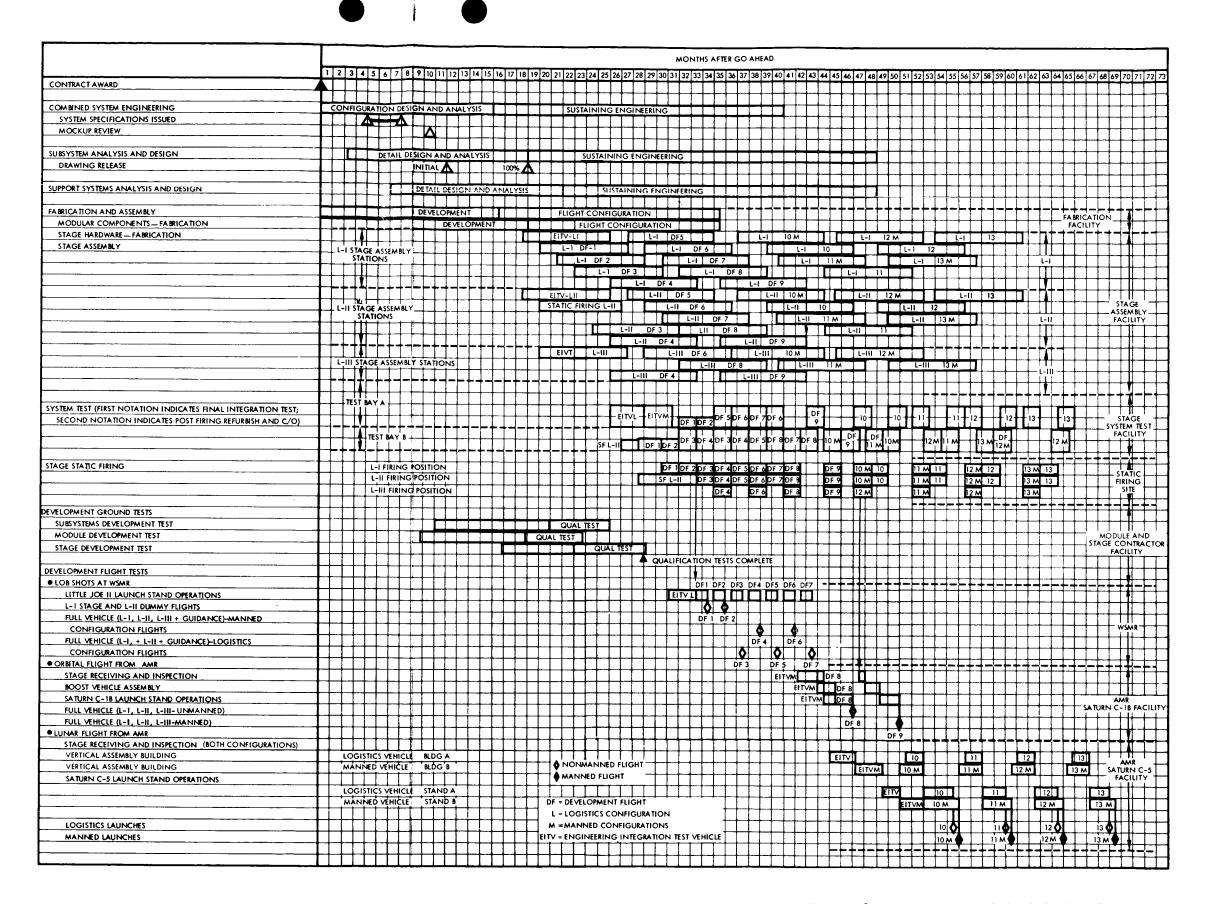


Figure 3-9. Program Schedule for Combined Logistic and Manned Tailored Lunar Spacecraft

program is essentially two spacecraft programs with only the complexity and man rating requirements superimposed on the double program. Very little can be shared between the two programs because of differences in configuration. Even the system engineering shares only the common interface of launch vehicle environment and physical design.

The only significant areas that may offer an increase in utilization due to combining the individual programs is in the static firing operation. It is conceivable that the two tailored vehicles could be fired from the same captive firing site with very minor changeover. However, this arrangement was not shown because of the unknown location of stage contractors. It is assumed that the static firing site would be close enough to the stage contractor to permit timely and effective support of the firings. Also, the transportation cycle from assembly to firing site to refurbish should be held to a minimum.

The Little Joe II launch site could also show an advantage in the combined program by sharing the launch pad and launch equipment between configurations. This was not considered in the program plan presented because the launch schedule dictates the requirement for two launch pads.

# 3.6.2 Comparisons Between the Modular Pair and Tailored Pair Program

The major similarity of the two pair programs is in the lunar launch operations phase. Each vehicle is launched independently from separate Saturn V launch stands on both programs. Similarity also exists during the orbital launch phase in that two manned configuration vehicles are launched independently of the logistic vehicles. Since the modular manned vehicle carries many components common to the logistics vehicle, an advantage may be realized by this additional test exposure that is not possible with the tailored pair program.

Major differences exist in the lob-shot development flight operation. The modular vehicles can share data on all flights on the L-I and L-II

stages. Sharing of modular ground support equipment and launch operations equipment is realized. None of these features are characteristic of the tailored vehicle pair program. One other difference, peculiar to the schedule chosen, is the fact that the modular pair is launched from a single test site. If the schedule time were shortened, two sites would be required by the modular vehicles. A requirement to decrease the schedule time and adapt from a logistic to a manned configuration between launches would eliminate the advantage of the modular concept in this regard.

In other program aspects the two concepts also differ extensively. The advantage of the modular pair is especially apparent in the assembly, system test, and static firing phases. Because of the higher utilization of common equipment and shared facilities the modular concept achieves a very distinct advantage. However, the advantage can only be realized in terms of cost savings and not time, because the sharing does not eliminate pacing operations.

It can be seen that the advantages of the modular concept are closely related to the parameters of the program plan. Changes in schedule in the facilities available, and in the location of facilities may have various effects on the advantages of the modular concept. Application of the concept to a series of programs supporting various missions with few flights per mission would evidently result in even more significant advantages for the modular concept.

#### REFERENCES

- 3-1 "Study of Spacecraft Bus for Lunar Logistics System,"
  8689-6006-TU000, performed by Space Technology Laboratories,
  Inc., under Contract NAS w-530; December 22, 1962.
- 3-2 "Lunar Logistic System," MTP-M-63-1, George C. Marshall Space Flight Center; March 15, 1963, vol I-XI.

# 4. COST ANALYSES AND COMPARISONS

Section 3 presents detailed program plans for both the tailored and modular pairs. Within the funding limitations of the contract it was not possible to accomplish such detailed planning on all of the configurations studied, nor was it felt to be necessary. For the other configurations the planning was limited to that necessary for cost estimating. In this planning certain concepts were utilized which were developed during the detailed planning on the modular and tailored pairs. These included the use of common facilities for module development and fabrication and reduced testing requirements for subsequent modular configurations after the module had been developed.

This section presents, in some detail, the cost estimates for eight lunar spacecraft programs:

- a) Modular Logistics Spacecraft, Figure 2-3
- b) Modular Manned Spacecraft, Figure 2-4
- c) Tailored Logistics Spacecraft, Figure 2-1
- d) Tailored Manned Spacecraft, Figure 2-2
- e) Hybrid Logistics Spacecraft, Figure 2-5 (modular L-I, tailored L-II)
- f) Hybrid Manned Spacecraft, Figure 2-6
- g) Single Stage Logistics Spacecraft, Figure 2-7
- h) Hybrid B Manned Spacecraft, Figure 2-8

In addition the costs for development of the module are presented.

The costs presented in this study are based upon the costs developed in Reference 3-1 for the C-5 configuration and are therefore subject to the same limitations as those costs. The estimates are presented in the form of cost matrixes which segregate the costs both by subsystem and by task or function to permit maximum analysis and comparison.

The matrixes are presented for the individual configuration programs; however, the costs for the vehicle pairs may be obtained by summation of the matrixes.

Each estimate is discussed separately and the information pertinent to comparison of that estimate with the others is included in this discussion. The cost matrix presented for each configuration does not include the effects of the 90 percent learning curve which has been assumed to be effective for all cases. After the costs had been estimated the learning curve was applied as discussed in Section 4.11.

The ground rules and assumptions which apply to all estimates are discussed in the next section.

#### 4.1 GENERAL

## 4.1.1 Ground Rules

In general, the estimates in this report are subject to the same ground rules used in Reference 3-1 and these are repeated here. However there are two major differences. Two of the areas in which significant cost advantages will accrue through the use of the modular concept are those of reduced testing and reduced facility requirements. For this reason, the costs of principal facilities and development flight test boosters have been included in the cost estimates. An exception to the latter is that the costs of Saturn IB boosters are not included. (At the request of NASA (MSFC) a special estimate has been included for the costs of the tailored and modular pair programs assuming all flight testing is accomplished using Saturn IB and Saturn V boosters. This estimate is presented in Section 4.7.) This does not affect the comparison since the same number (two) are required for all pair programs.

Other specific ground rules are:

a) Primary emphasis is placed on comparative estimates rather than absolute magnitudes. The objective is to approach an accuracy of + 10 percent on comparative

estimates whereas the absolute value of each estimate may not be closer than + 25 percent.

- b) No allowances have been made for changes to the spacecraft or to the program after contract inception.
- c) No allowances have been made for extraordinary development problems which would increase the amount of testing required and thus extend the program.
- d) Contractor's fee/profit has not been included.
- e) Direct Labor Rates The following average labor rates were utilized:

	\$ Rate 1 Man Year
Engineering	10,874
Tooling	7, 957
Manufacturing	8, 182
Test and Operations	10, 164

f) Overhead and General Administrative Rates - The following indirect rates were utilized:

Overhead, Engineering 90 percent of direct labor dollars

Overhead, Manufacturing 115 percent of direct labor dollars

General and Administrative Expense 85 percent of total cost prior to application of G and A

- g) The estimate for each configuration includes four operational vehicles in addition to the test articles required for development, except where otherwise specified.
- h) The fact that half of the programs considered in this study are for manned configurations has been taken into account to some extent in the program planning. It has been assumed, however, that most of the development of the crew-related systems will have been completed prior to their use in this program. Specific items not included in these estimates are:
  - Costs of the Apollo command module or its equipment.

- 2) Test programs to man-rate the return stage engines. (This testing accomplished on these engines by the time period of interest may make this unnecessary.)
- 3) Crew training and display development programs.

The estimates do consider, however

- Utilization of portions of the command module guidance, attitude control, and thermal control equipment.
- 2) Tests of crew, command module, and landing stages to approach and land on the moon.
- 3) Earth orbital flights of manned configurations.
- i) In estimating the costs of the modular pair, it is assumed that the L-I and L-II stages are identical for both configurations and that the development costs are incurred in the modular logistics program only.
- j) In estimating the costs of the modular pairs it has been established that, by proper contractor arrangement and program planning, the programs may be integrated to reduce facility requirements and obtain other program advantages. The estimate for this pair assumes such an integrated total program.
- k) The tailored pairs, due to the differences between the configurations, do not lend themselves to such an integrated program. It is assumed, therefore, that the programs for these pairs are conducted concurrently and are essentially unrelated. No allowances for commonality between configurations has been included for these pairs.
- A 90 percent experience curve has been utilized in all configuration cost estimates. It was assumed that this curve would become effective after five vehicles had been constructed. In the case of the modules, the curve was applied to these separately.

## 4.1.2 Cost Matrixes

The ordinate of the cost matrixes used in preparing the estimates presented in this study consists principally of subsystems and as such is self-explanatory. The abscissa, however, consists of a series of functions or task breakdowns; a brief description is given in the following paragraphs.

## 4.1.2.1 Program Management

The overall technical management and control of the program, including the primary responsibility of overall program planning, scheduling and budget control. Key decisions include configuration selection, and "freeze" for the major elements defined by system engineering such as that of stages, support systems, and facilities. The program management activity begins with the initial organization required to implement the program plan and extends throughout the development and manufacturing phases.

# 4.1.2.2. System Engineering

The engineering activities involved in overall system design and analysis, include:

- 4.1.2.2.1 Advance Planning. Preparation of plans for the design test, facilities aquisition, manufacture, and transportation.
- 4.1.2.2.2. Analysis Activities. These include configuration analysis, model testing program plan optimization study, performance and trajectory analysis, reliability assessment and analysis, system guidance and control analysis, support subsystem analysis, etc.
- 4.1.2.3 <u>Design Activities</u>. These include preliminary system design, detail system configuration definition, and providing technical liaison and support to subsystem design.

4.1.2.2.4 <u>Control Activities</u>. These include establishing detail program plan from subsystem inputs; preparing and maintaining system performance specification, interface specifications, and the engineering data book; weight control; mock-up review; and providing management reports and PERT inputs.

# 4.1.2.3 Subsystem Analysis and Design

Subsystem analysis and design includes the detail engineering effort required for each subsystem listed; analysis work specifically associated with the stage or modular subsystems; and provides support of all activities required to support the preparation and release of manufacturing drawings.

# 4.1.2.4 Development and Design Verification Testing

This includes the necessary development testing to provide data in support of detail design and the design verification testing required to demonstrate the performance of the design chosen; such tests as breadboard testing, vibration surveys, structural testing, landing gear deployment demonstration, etc.; the cost of materials, and the cost of the test articles; but does not include full system testing.

# 4.1.2.5 Specifications

This includes the physical assembly, preparation, publication of data in specification format, and the management control of specification data.

# 4.1.2.6 Engineering Data and Reports

This includes the preparation and issuance of all necessary engineering documentation and test reports; but does not include engineering drawings or manuals (included under Analysis and Design) or specifications.

## 4.1.2.7 Reliability

This includes the effort utilized in the establishment of reliability goals, the analysis to verify reliability attainment, and the management of the engineering efforts directed toward a Reliability Program. Effort and components used in testing for reliability are included under various test categories, but principally under development testing.

## 4.1.2.8 Quality Assurance

Quality assurance includes the management and engineering activities required for assurance of the quality of the end item.

#### 4.1.2.9 Fabrication

Fabrication includes the effort involved in procurement and fabrication of ground test and flight hardware to the component and subsystem level; includes GSE; but does not include stage or module assembly and checkout. Recurring fabrication costs for operational phase are separated.

# 4.1.2.10 Assembly Integration and Checkout

Included are the final assembly of subsystems into an integrated stage and completion of tests to demonstrate satisfactory function of the stage, as well as the static firing test stages, engineering integration test vehicle, and all flight articles. The effort also includes the preparation of procedure, reports, etc., and materials required for the testing.

# 4.1.2.11 Tooling and Special Test Equipment Design

This includes the design necessary to develop all jigs, dies and manufacturing aids required for all end item hardware. In addition, the design of electrical special test equipment used in the factory is included in this category.

# 4.1.2.12 Tooling and Special Test Equipment Fabrication

This includes the fabrication effort necessary to manufacture all jigs, dies, and manufacturing aids. In addition, this category includes all GSE and special test equipment required in the factory.

## 4.1.2.13 Qualification Test

This includes the necessary component and stage tests required to demonstrate compliance with design performance under maximum limit environments, and applies to qualification test articles only.

## 4.1.2.14 Acceptance Test

This includes the necessary component and stage tests required to demonstrate satisfactory performance and freedom from manufacturing fault under nominal environments and applies to all flight articles.

## 4. 1. 2. 15 Off-site Test

This includes the cost of all captive static firing tests and the WSMR lob-shot flights, as well as facilities modifications and Little Joe booster costs.

# 4.1.2.16 Launch Operations

This includes the launch site operations required to prepare for, checkout, and launch the orbital and lunar flights from AMR; post launch analysis and reports; stand and blockhouse modifications; but does not include the cost of launch sites.

# 4.1.2.17 Logistics

This is a general term covering four distinct categories of activity: the <u>training</u> of operations and maintenance personnel (including NASA personnel) in the necessary knowledge of system, subsystem, and component design characteristics; the collection of data for, and the preparation and issuance of <u>handbooks</u> and <u>manuals</u> necessary to support all system maintenance and flight operations support; the physical work of

performing maintenance on the spacecraft and its components in support of the test program or operational missions; and the <u>spare parts</u> manufacture, distribution, stocking, and record-keeping needed to support the program maintenance effort.

## 4.1.3 Comparative Program Data

This section of the report contains program data in a summary form for all programs so that comparisons between programs can be made easily. Collection of the data into a single section also increases the ease with which it may be located.

The major program factors which vary among the programs are the number of vehicles required for the program; this in turn is affected by the number of development flight test vehicles required and the facility requirements. Table 4-1 is a summary of the development flight test programs for all the programs considered. This table summarizes the flights, the conditions of each stage for each flight, the condition of the guidance system and, for the manned configurations, the condition of the Apollo command module as well as whether the flight is manned or unmanned. It is apparent from this table that the modular concept results in reduced flight test requirements.

Table 4-2 summarizes the facility requirements for each program. In planning all programs utilizing modular configurations, it was assumed that complete development and facility provisioning were obtained in the logistics programs and that only the necessary additional development and facilities were provided in the manned programs. In Table 4-3 the facility requirements of Table 4-2 have been translated into facility costs. These costs are for brick and mortar only. The costs of GSE to equip these facilities are estimated in each cost matrix.

Table 4-4 summarizes the total number of vehicles required for each program considered. The flight test vehicles of Table 4-1 are included in this table as well as the engineering integration test vehicles,

Table 4-1. Flight Test Summary - All Programs

	Manned	t	t		•	1	•				No	No	No	Yes
	Apollo	1	t		-	1	t				Semi-Live	Semi-Live	Live	Live
Modular	Guidance	No	N.		٧٠٥	Yes	se N				Yes	Yes	Yes	Yes
	111-111	•	ı		1	-					Live	Live	Live	Live
	L-II	Dummv	Dummy		Live	L:v	Live				Live	Live	Live	Live
	L-1	Live	ive		Live	. vi.!	Live				Live	Live	Live	Live
	Manned	1	•	ı	t		1	0 Å	No	0.X	Ŋo	No	No	Yes
	Apollo	ı	-			ı	ı	Durwe.	Dummy	Semi-Live	Semi-Live	Semi_Live	Live	Live
Tailored	Guiďance	o'X	04	Yes	Yes	Yes		SN.	No	Yes	Yes	Yes	Yes	Yes
Taj	II-1	Dummy	Dunimy	Live	L'v	Live	Liv	Pededid	Dummy	Live	Live	Live	Live	Live
	L-I	Live	Live	Dummy	Liv	> 1	Liv	7.1	Live	Durimy	Live	Live	Live	Live
Booster	<b>.</b>	Little joe	Little Joe	Little Joe	Little Jor	Táttle Joe	Lattle Joe	1 .rrl · Lo.	Little Joe	Littl: Joe	List Low	Little Joe	Sature IR	Saturn IB
Mission				ន១រុ	nsigor	I					рэци	кM		

Table 4-1. Flight Test Summary - All Programs (Continued)

	Manned	•			-		,				No	No	No	Yes
	Apollo	_			ı	1					Dummy	Semi-Live	Live	Live
B Manned	Guidance	ON			хех	Yes	Yes				Yes	Yes	Yes	Yes
cs and Hybrid	L-III	•			-	ş	•				Live	Live	Live	Live
Single Stage Logistics and Hybrid B Manned	L-II	ı			1 -	1	,				Live	Live	Live	Live
Single	I-1	Live			Live	Live	Live				Live	Live	Live	Live
	Manned	-	-	-	1	,	ı	No		No	No	No	oN	Yes
	Apollo	-		1	-	1	1	Dummy		Dummy	Semi-Live	Semi-Live	Live	Live
Hybrid	Guidance	No	No	Yes	Yes	Yes	Yes	No		Yes	Yes	Yes	Yes	Yes
	וי-ח	Dummy	Dummy	Live	Live	Live	Live	Dummy		Live	Live	Live	Live	Live
	L-I	Live	Live	Dummy	Live	Live	Live	Live		Dummy	Live	Live	Live	Live
Booster		Little Joe	Saturn IB	Saturn IB										
Mission				tics	sigod					1	рə	nns <b>M</b>		

Table 4-2. Facility Requirements

		Number of E	Number of Facilities Required	ed		
Configuration	To of our A comply	Factory Test				
	Factory respensely	C/C Vertical	Static	Development	nent	Operational
	Stage Assembly	J/O verticar	+ + + + + + + + + + + + + + + + + + +	Tlight Test	α. +	Launch
	Station	Test Bays	lest	1 11811		
				Little	Saturn	
				Joe	IB	
Madilon I orietion	œ	2	3	1	1	1
Modular Logistics	)		1 Dual Stand			
			1 Single Stand			
Modular Manned	5 Additional	0 Additional	<pre>1 Single Stand Additional</pre>	0 Add	-	1 Add
	œ	2	4	-	ı	1
Tailored Logistics	<b>)</b>		2 Dual Stands			
Tailored Manned	8 Additional	2 Additional	4 Additional 2 Dual Stands	1 Add	-	1 Add
						ŗ.
Hybrid Logistics	∞	2	2	_	ı	<b>-</b>
Hybrid Manned	6 Additional	1 Additional	l Additional	1 Add	-	1 Add
Single Stage Logistics	9	2	2 Single Stands		1	-
Hvbrid B Manned	5 Additional	1 Additional	1 Additional	0 Add	1	1 Add
				,		

Table 4-3. Facility Cost Summary (\$000)

Facility Costs\*

Configuration	Factory Assembly and System Test	Static Test	Development Flight Test	Operational Launch	Total
Modular logistics	9, 907.5	1,620.0	630.0	580.0	12, 737.5
Modular manned	3, 987.5	710.0	200.0	580.0	5, 477.5
Tailored logistics	9, 907.5	1,820.0	630.0	580.0	12, 937.5
Tailored manned	10, 126.0	1,820.0	630.0	580.0	13, 156.0
Hybrid logistics	9, 907.5	1,820.0	630.0	580.0	12, 907.5
Hybrid manned	7,750.0	910.0	630.0	580.0	9,620.0
Single stage logistics	7, 420.0	1, 420.0	630.0	580.0	9,050.0
Hybrid B manned	4,750.0	910.0	260.0	580.0	6,500.0

\* Brick and mortar costs only

Table 4-4. Number of Vehicles Required

		Requi	rement	
Configuration	EITV	Static <u>Test</u>	Development Flight Test	Operational Vehicles
Modular logistics	l Complete S/C	l L-II Stage	2 L-I Stages and Durnmies	4 Complete S/C
			3 Complete S/C	
Modular manned	l L-III Stage	l L-III Stage	4 Complete S/C	4 Complete S/C
Tailored logistics	l Complete S/C	1 Complete S/C	2 L-I Stages and Dummies	4 Complete S/C
			l L-II Stage and Dummy	
			3 Complete S/C	
Tailored manned	1 Complete S/C	l Complete S/C	2 L-I Stages and Dummies	4 Complete S/C
			l L-II Stage and Dummy	
			4 Complete S/C	
Hybrid logistics	1 Complete S/C	l Complete S/C	2 L-I Stages and Dummies	4 Complete S/C
			l L-II Stage and Dummy	
			3 Complete S/C	
Hybrid manned	l L-II Stage	l L-II Stage	l L-I Stage and Dummy	4 Complete S/C
			l L-II Stage and Dummy	
			4 Complete S/C	
Single stage logistics	1	1	4	4
Hybrid B manned	l L-III Stage	l L-III Stage	4 Complete S/C	4 Complete S/C

any static firing test vehicles, and the four operational vehicles provided in each program. The costs for any additional test hardware for subsystem testing is contained in the development costs of the particular subsystem.

## 4.2 MODULAR LOGISTICS CONFIGURATION

The underlying principle in the modular concept is that the use of such a major common element across several mission applications can lead to significant reductions in the overall development effort without an overbalancing loss in vehicle performance. The program and contractor relationships which maximize these reductions are explained in detail in section 3.2. Table 4-5 is a cost matrix for this program.

This estimate takes into account the fact that the module and its associated support equipment need be developed only once and can then be used in both stages with a minimum of development plus integration testing. The total costs for the module development program are included in the L-I stage estimate; the estimate for the L-II stage contains only the recurring costs plus the additional development and integration costs necessary for adapting the module to this stage.

Table 4-4 summarizes the total number of vehicles required for this program as well as the other programs. The number of vehicles required is, of course, a major factor in the total cost.

Other major areas of interest, from a cost analysis standpoint, include static testing, development flight testing, facilities and the vehicle configuration. These areas are discussed separately.

# 4.2.1 Static Testing

The static firing test program for this configuration takes advantage of the module concept in that a single static firing stand, located at the module contractor's plant is sufficient for development testing of the module for both stages. One additional "dual" static stand (as described in Reference 3-1) which has the capacity for testing two stages

Table 4-5. Modular Logistics Configuration Program Cost Matrix

	<del></del>							istics Config		grani Cost I	VIGITIX	<b>.</b>							
				ENGINI	EERING					TOOI	LING AND M	ANUFACTU	RING			TEST AND	OPERATION	s	
Stage/Subsystem/Item	Program Mgmt	System Engr	Analysis and Design	Dev Testing	Specifi- cations	Engr Data and Report	s Reliability	Quality Assurance	Tooling Design	Tooling Fabrication	Production Fabrication	Spacecraft Assembly	Spacecraft Accep. Test	Quality Control	Qualifica- tion Test	Offsite Test	Launch Operations	Logistics	TOTAL
Spacecraft	31,616.6	10,055.4	1,054.3	2, 173. 6	438. 3	7,167.5	17,443.4	8, 420.6				2,737.1	8,069.2	8, 252, 5	42.8	15, 364, 9	10, 238, 6	16, 915, 9	139, 990, 7
Mockup		25.9	175.8					1			43, 2		9,007.		<del></del>	13,301. /	10,250.0	10, 713. 7	244.9
L-II Stage		2,508.0	,									9, 103. 3	1,058.7		45.4	511.2	311.9		13, 538. 5
Structure			7,220.0	5, 459.2	_		†	1	1,735.9	4,083.4	26, 514. 8		·		246.8	13.0	38.9		45, 312.0
Propulsion			2, 328. 3	1,315.4			† <del>-</del>	<del></del>	93.0	613.9	15, 182.0	35.4	350.4		220.0	522.0	948.2		21,608.6
Thermal Control		1	1,850.0	750.0	İ	<del> </del>	<del>                                     </del>	<del></del>	64.9	129.0	<del></del>		<del> </del>		9.4	41.3	41.2		<u> </u>
Attitude Control		1	1,995.4	639.5		†	<del></del>	<del></del>	73.7	338.4	3, 105. 8		290.9		160.1	.110.8	791.1		5,621.8 7,505.7
Guidance System		1	19,042.6	22, 125. 9		<del></del>	<del></del>	+	43.2	649.9	<del></del>	213.8	735.5		43.5	1,768.9	2,771.3		L
Electrical Power			2,637.4	1, 109. 9	<del>                                     </del>	<del></del>		+	506.2	957.5	+		686.6			+	<del>+</del>	!	58, 882.5
Communications & Telemetry			2, 104.1	363, 5	<del> </del>	<del> </del>	ļ		213.9	1,076.1		6.4	728.3		401.7	64.6	76.6		11,621.8
Total L-II Stage		2,508.0	37, 177. 8	31,763.4		<del> </del> -	<del> </del>	- <del></del>			4, 177. 3				318.6	122.5	164.2		9, 268. 5
L-I Stage		927.7	<del></del>	<del>+</del>		<del> </del>	<del>       </del>	<del> </del>	2,730.8	7,848.2	68, 378. 7	9,358.9	3,850.4		1,445.5	3, 154. 3	5, 143. 4		173, 359.4
Structure		961.1	5, 136, 8	40.0		<del> </del>	ļ	<del></del>				1,751.8				12.0	207,9		2.939.4
Propulsion		· · · · · · · · · · · · · · · · · · ·	6, 093.1		<del> </del>		ł	<del></del>	999.8		12,427.2				60.0	5,0			25,058,6
Thermal Control				4, 154. 8		· · · · · · · · · · · · · · · · · · ·	<del>   </del>		930.1		15,283.8	34.2	350.4		2, 195.6	1,777.4	948.2		34,837.3
Guidance System	<del></del>		2,500.0	1,950.0	<del></del>				353.0		1,080,8				9.4				6, 292. 5
Electrical Power	<del></del>	· · · · · ·	177.2	1,614.5	<del></del>	<del></del>	<del>                                     </del>		62.8	614.5			176.7		15,6				6,547.9
Total L-I Stage	<del> </del>	027.5		114.3		ļ			108.0	115.5			155,1		79.8				3, 963. 8
Mechanical GSE	<del></del>	927.7	16, 131.3	11,891.5		<u> </u>		<u> </u>	2,453.7	6,559.4	33, 845. 3	1,786.0	682.2		2,360.4	1,816.7	1,185.3		79,639.5
L-II Stage		156.7														41.0	80.0		277.7
L-II Stage		· · · · · ·	1,960.7	371.0					101.0	157.3	5, 526.2				253.0				8, 369, 2
	· · · · · · · · · · · · · · · · · · ·	ļ. ·	2,748.2	476.8			ļ	*.	131.0	212.3	5, 526, 2				273, 0	41.0	80.0		9, 488, 5
Electrical GSE		118.3	5,281.6	2,033.0					328.7	462.1	20,216.9					701.9		1	29, 820.4
Electrical Special Test Equipment Special Facilities		40.2	889.8							24,051.4					1 .				24, 981, 4
Special Facilities		· · · · ·	<del> </del> -			<del> </del>					12,737,5								12,737.5
TOTAL	31, 616, 6	13, 832, 2	65, 419. 5	48,709.3	438.3	7, 167, 5	17, 443, 4	8, 420. 6	5,745.2	39, 290, 7	146,274.0	13,882.0	12,601.8	8, 252.5	4, 374.7	21, 119. 8	17, 405. 2	16, 915. 9	478, 909. 2
·																			,
								1											

concurrently, is adequate for both stage development and operational testing. For stage development static firings the only static test vehicle required is one L-II stage (Table 4-4). This results from the fact that with the module concept, the less complex L-I stage static test program becomes small enough so that it can be conducted on one of the flight articles.

## 4.2.2. Development Flight Testing

This element of the development program which is summarized in Table 4-1 also takes advantage of the module concept. The flight test program is initiated by two Little Joe lob-shot flights of the L-I stage with a dummy L-II stage. After proving that this stage (hence the module) is flight-worthy, the program proceeds immediately to tests of the complete spacecraft which will provide testing with respect to guidance, attitude control, spacecraft dynamics, propulsion, etc. The complete flight test program will consist of three flights of the latter type. This program will provide eight propulsion system tests and three guidance system tests as compared with five L-I propulsion system tests, four L-II propulsion system tests and four guidance system tests in the tailored logistics program. Orbital or lunar test flights of this spacecraft are not believed to be warranted for the logistic configuration if the development test programs recommended herein are completed with satisfactory results. Considering the tremendous costs associated with such tests, it appears that the first space flight should be an operational flight instrumented so that test results can be obtained during the flight. This instrumentation should be complete enough to make failure analysis possible in the event of a failure.

## 4.2.3 Facilities

The number of facilities required for this program as well as the other programs is summarized in Table 4-2. The corresponding costs for these facilities are summarized in Table 4-3. The requirements

for these configurations are established in Section 3. The principal facility difference between this program and the tailored programs is the requirement for a single and dual static test stand instead of two dual stands as already discussed (Section 4.2.1).

The facility costs are included in the cost matrices.

## 4.2.4 Ground Support Equipment (GSE)

The ground support equipment required for this configuration is similar to the C-5 configuration of Reference 3-1 with the following principal exceptions. The propellants and engines used in the L-II stage of Reference 3-1 are different from those in the L-II stage of this vehicle, therefore the propellant loading and storage equipment will be different. The tank configuration of both stages is also different, requiring some changes in handling and transporting equipment. Although these differences are important physically they have a small effect from a cost standpoint.

Those portions of the equipment which are module-peculiar, that is require no development for the stages in which the module is used, have been established for both the electrical and mechanical GSE. As with the vehicle hardware the development costs for these items have been included in the L-I costs and only that portion requiring modification due to the different size tanks of the L-II module are included against that stage.

## 4.2.5 Configuration

The modular logistics configuration Figure 2-3 is a two stage configuration which utilizes the module in both stages. The costs have been estimated for a program in which the module in the L-I stage will require a complete development program. With this development accomplished, it is estimated that only 10 percent of the design, analysis and development testing required for the L-I stage module will be required for the L-II stage module. The latter differs from the former only in the length of the tanks.

A major cost factor which causes the L-II stage structural costs to be appreciably higher than the L-I stage, is the extremely large landing gear required for this configuration. Both the gear and the stage structure required to support the gear cause the costs to increase.

#### 4. 3 MODULE COSTS

One of the principal areas of interest in this study is an estimate of the possible cost savings if the module is utilized on other space missions. As explained in Section 4.4, the best way to accomplish such an estimate is to cost out and compare the complete programs for the different missions including facilities, test vehicles, test hardware, etc. In such an estimate, however, it becomes very difficult to isolate the effects of the module due to the presence of other changes in the vehicle or program. For this reason the development costs for the modular hardware items of the L-I stage of the modular logistics configuration have been itemized separately in Table 4-6.

The total costs in this table include all costs for the development and fabrication of the module and module-peculiar GSE for the L-I stage of the modular logistics configuration.

The delivered hardware costs include the costs for the module and module-peculiar GSE hardware which was delivered for the ten L-I stages and supporting GSE respectively. The supporting GSE was that necessary to equip the facilities necessary to the program.

The difference between these two categories of costs constitutes the module and module-peculiar GSE development costs.

## 4.3.1 Structure-Engine Attachments

These are the only elements of structure (as defined in this report) which are included in the module.

Table 4-6. Module Costs, Modular Logistics Configuration L-I Stage \$ 000

Development	¢ 2 205 4	7.001,1	( 7 10 )	6,814.1	3, 865. 6	48.3	671.6	1,800.0	410.1	\$16,608.0	1,008.2	3, 196. 7	6,340.3	1		1 ()	168.2	\$10,713.4	2, 235.6	1,779.3	944, 4	\$ 4,959.3	ł	\$32, 280. 7
Delivered	Hardware Costs	\$ 564. U	16.2	139. 1	1 1	1	67.2	1	615.2	\$ 1,401.7	1	1	15 526.6	2 0 0 0	5.4.3	350.4	836.6	\$16,742.9	,	103.4		4 1 218 7	,	\$19,363.3
Total	Cost	\$ 2,769.4	809. 1	6,953.2	3,865.6	48.3	738.8	1,800.0	1,025.3	\$18,009.7	1,008.2	3, 196. 7	2) - 2, - 3	61,800.7	29.3	350.4	1,004.8	\$27, 456.3	7 326 6	2, 233.0	1,006.1	2,059.7	0.01.00	\$51,644.0
		Program Management	System Engineering	Analysis and Design	Audiy 313 did 20218	Specifications	Specifications	bag, Data and regers.	Condition Acourance	Sub-Total Engineering	Tooling Dooring	TOUTING DESIGN	Tooling Fabrication	Production Fabrication	Spacecraft Assembly	Space raft Acceptance Test	Spaceciair incoprance	Quality Control	0.	Qualification Test	Offsite Test		Sub-Total Test and Operations	TOTAL COST

## 4.3.2 Propulsion

All the items of hardware of the propulsion system are part of the module with the exception of the tank walls (non-modular propulsion).

These include:

- a) RL-10 engines
- b) LO<sub>2</sub> feed system
- c) LH<sub>2</sub> feed system
- d) Pressurization system (including tanks)
- e) Propellant utilization system
- f) Electrical cabling and junction boxes
- g) Engine gimbaling system
- h) LO<sub>2</sub> and LH<sub>2</sub> tank ends

# 4.3.3 Mechanical Ground Support Equipment (GSE)

The mechanical GSE, which can be considered as modular, is not, in all cases, directly useable with modules having different sizes of tanks. However, it can be utilized with minor modification. Equipment falling in the directly applicable category includes engine slings, engine assembly lifts, etc. That which may require some modification will include tank slings, propellant transfer equipment, pneumatic test console, pneumatic pressure and control equipment, etc. An estimate of the costs of this equipment is included under "Modular Mechanical GSE."

# 4.3.4 Electrical Ground Support Equipment (GSE)

The electrical GSE, like the mechanical GSE also may not be directly useable with all modules. However, it also may be utilized with minor modifications. Items of electrical GSE considered modular are the propellant loading sections of the launch control equipment and the propulsion power supply.

## 4.4 TAILORED LOGISTICS CONFIGURATION

This configuration (Figure 2-1) is very similar to the C-5 configuration of Reference 3-1. Since the cost estimates of Reference 3-1 form the basis for the estimates in the present study, the estimate for this configuration is very similar to the C-5 estimate. The estimate for the tailored logistics configuration, which is presented in Table 4-7 is based upon the total number of vehicles shown in Table 4-4.

## 4.4.1 Static Testing

As indicated in Table 4-2, the static firing test program for this configuration requires two dual static firing stands. Inasmuch as each stage has a different type of propulsion system, both stages are required in the static test article.

## 4.4.2 Development Flight Testing

This phase of the development program requires six Little Joe lob-shots consisting of two L-I stage flights with dummy L-II stages, one L-II stage flight with a dummy L-I stage, and three flights of the complete spacecraft (Table 4-1). This is one less flight of the L-I stage alone than was planned in Reference 3-1. This program provides five L-I stage propulsion system tests, four L-II stage propulsion system tests and four guidance system tests.

## 4.4.3 Facilities

The facility requirements for this program are shown on Table 4-2. The requirements are similar to those for the modular logistics program with the exception of the two dual static firing stands mentioned in Paragraph 4.4.1 rather than the one dual and one single stand.

# 4.4.4 Ground Support Equipment (GSE)

The amount of GSE required is that necessary to support the facilities of Paragraph 4.1.2. The equipment is described in some detail in Reference 3-1, hence, the description is not repeated here.

Table 4-7. Tailored Logistics Configuration Program Cost Matrix (\$000)

		T	T	ENGINE	ERING	<del> </del>				тоо	LING AND N	MANUFACTU	JRING		Т	EST AND C	PERATION	s	
Stage/Subsystem/Item	Program Mgmt	System Engr	Analysis and Design	Dev Testing	Specifi- cations	Engr Data	Reliability	Quality Assurance	Tooling Design	Tooling Fabrication	Production Fabrication	Spacecraft Assembly	Spacecraft Accep. Test	Quality Control	Qualifica- tion Test	Offsite Test	Launch Operations	Logistics	TOTAL
Spacecraft	31,117.5		1,054.3	2,173.6	477.8	7,054.3	17.168.0	8.050.2				2,737.1	8,069.2	7,889.5	42.8	15.846.7		16,171.8	138,146.
Mockup		25.9	175.8					J.070.1.			43.2		0,009.2	1,009.5	42.0	15.040.7	10,230.6	16.171.0	
L-II Stage		2,508.0		210.2							1	6.741.2	1,342.8		45.4	F00 0	277.0		2 <u>1</u> 14.
Structure			6,731.3	3,528.2					944.3	2,312.2	7,184.2	<u>U.141.6</u>	1,342.0		123.4	589.8 15.0	311.9		11,749.
Propulsion		<u> </u>	3,653.0	2,424.7			Ì		150.8	451.4	8,094.1	13.8	168.0	·			38.9		20,877.
Thermal Control			2,451.3	540.0					64.9			13.0	100.0		1,341.6	902.6	358.9		17,558.
Attitude Control			1,776.6	579.6				†		129.0	3,344.0				9.4	47.7			6,586. 7,832.
Guidance System			19,042.6	22,125.9	**	<del> </del>		<del> </del>	73.7	338.4	3,796.0		200.0		149.3	127.9	791.1		7,832.
Electrical Power			2,637.4	1,109.9		· · · · · · · · · · · · · · · · · · ·		<del> </del>	43.2	649.9	12,764.5	237.5	898.9		43.5	2,041.1	2,771.3		60,618.
Communications & Telemetry			2,104.1	363.5		<del> </del>		<del> </del>	506.2	957.5	5.749.7	7.7	839.1		401.7	74.5	76.6		12,360.
Total L-II Stage		2,508.0	38,396.3	30,882.0		<del>                                     </del>		<del></del>	213.9	1,076.1	4,177.3		728.3		318.6	141.3	164.2		9,287.
L-I Stage		1,392.7	30,390.3		*		-	<del>                                     </del>	1,997.0	5,914.5	45,109.8	7,000.2	4,177.1		2,432.9	3,939,9	4,512.9		146,870.
Structure		19.372.1	7,504.9	70.0 6,155.3		<del> </del>		<u> </u>			ļ	3,345.5				38.2	207.9		5,054.
Propulsion			7,797.3	5,042.8		<del> </del>		<del>                                     </del>	1,735.9	4,111.6	22,024.0				81.2	14.0	29.2		41,656.
Thermal Control		† <del></del>	2,400.0	1,930.0		<del> </del>		<del> </del>	1,094.3	3,709.0	24,277.0	40.3	432.4		3,326,9	1,658.9	923.9		48,302.
Guidance System		<del>                                     </del>	2,224.2	1,614.5		<del></del>		<del> </del>	353.0	377.7	1,188.9				9.4	20.8			6,279.
Electrical Power System		<del> </del>	177.2	114.3		<del> </del>		<del>                                     </del>	62.8	614.5	2,023.6		176.7		15.6				6,731.
Total L-I Stage		1,392.7	20,103.6			<del> </del>	<del>-</del>		108.0	115.5	3,535.3		189.6		79.8				4,319.
Mechanical GSE						<del> </del>			3,354.0	8,928.3	53,048.8	3,385.8	798.7		3,512.9	1,731.9	1,161.0		112,344.
L-II Stage		159.9	78.9	34.6			<u> </u>							ł	·	81.8	157.2		512.
L-I Stage			2,542,7	353.5					125.8	176.3					197.3				5,441.
Electrical GSE		110 2	2,782.8	502.2			<del></del>	<b> </b>	131.0	212.3	5,163.2				253.0				9.044.
Electrical Special Test Equipment		118.3	5,285.0	2,032.9		<u> </u>		·	328.7	462.7	20,216.9					701.9	677.9		29,824.
Facilities		40.2	889.8			ļ	<u> </u>	ļ		24,051.4							```		24,981.
T. D. A. C.						ļ					12,937.5								12,937.
TOTAL		-1 1			<del></del>	<u> </u>													
	31,117.5	14,300.4	71,309.2	50,905.7	477.8	7,054.3	17,168.0	8,050.2	5,936.5	39,745.5	138,565.5	13,123.1	13,045.0	7,889.5	6,438.9	22,302.2	16,747.6	16,171.8	480,348.
	l i					T		<del></del>	·		<del> </del>					··			

## 4.4.5 Configuration

This configuration (Figure 2-1) is a two-stage configuration utilizing two RL-10 engines in the L-I stage and three storable propellant engines in the L-II stage. It is very similar to the C-5 configuration of Reference 3-1 with the exception of the landing gear. The crushable pad type gear of the C-5 configuration is replaced by an extendable-leg type. The latter gear and its associated structure are quite heavy resulting in appreciable structural cost increases, which are offset to some extent by the requirement for one less L-II stage for flight test.

Since the C-5 cost estimate was prepared, a development program for the storable propellant engines has been initiated, hence, propulsion cost estimates have been reduced.

## 4.5 MODULAR PAIR, LOGISTIC AND MANNED SPACECRAFT COSTS

A variety of techniques for estimating the advantages, from a cost standpoint, which can be realized through the use of a modular concept have been considered. After reviewing and discarding several possible methods, it was decided that in order to obtain this information on a realistic basis, it is necessary to compare a pair of vehicles designed to perform the same missions, i.e., one pair using the module, the other pair tailored to secure the best possible performance for the mission. In this manner it is possible to evaluate all aspects of the comparison, the advantages as well as the disadvantages.

Table 4-8 is a cost matrix for the modular manned program (configuration SB-910). These costs, when combined with those for the modular logistics program (Section 4.2), comprise the costs of a pair of modular configurations for which the development programs have been integrated in order to obtain maximum utilization of all facilities and certain other program advantages. In this estimate it was assumed that, with the exception of certain subsystem changes, stages L-I and L-II are identical for both the manned and logistics configurations and

Table 4-8. Modular Manned Configuration Program Cost Matrix

	1	TOOL	ING AND M	ANUFACTU	RING		Т	EST AND C	PERATION	S	
Quality ts Reliability Assurance	Tooling Design	1	Production	Spacecraft	Spacecraft	Quality Control	Qualifica- tion Test	Offsite	Launch Operations		TOTAL
7 12,374.5 6.944.	1			3,737.1	9,069.2	6,805.6		13,000.0	10,238.6	13,949.9	118,067.
			64.8								367.4 7,044.2
				5,401.4				38.2	207.9		7,044.2
			23,568.5					14.0	29.2		24,606.6
			9,554.1	29.3	215.5			842.4	948.2		11,589.5
	3.5	37.7	864.6					44.5			1,700.3
	<del></del>	4.3									6,090.9
	10.8				137.9		8.0				2,768.4
<del></del>	14.3	53.5	2,571.1	5,430.7	353.4		8.0	939.1	1,185.3		53,799.9
		23.2	30,900.9	1,401.4	373.4		0.0	38.2	207.9		3,042.2
<del></del>	<del>-</del>	t	10 020 1	1,401.4	<del></del>		<b></b>				
<del></del>		<del> </del>	10,030.4	2). 2	03.5.5			14.0	29.2		10,781.9
<del></del>	3.5	37.7	9,368,6 864.6	34.2	215.5		<del></del>	842.4 20.8	948.2		11,408.9 1,676.6
1				+	7.05.0		0 0	20.0			2,768.4
<del> </del>	10.8			7 105 (	137.9		8.0				
<del></del>	14.3	49.2	22,834.7	1,435.6	353-4		8.0	915.4	1,185.3		29,678.0
		<del>                                     </del>			<del>j</del> -		<del> </del>				159.9
<del></del>			3,907.5				<b> </b>				3,907.5
		<del>                                     </del>	3,907.5				-			·	3,907.5
		<del> </del>	10,952.0				ļ				11,070.3
<del> </del>		1	6,103.3	4,058,7			45,4	589.8	277.0		13,827.3
	Old a	0.310.0		4,050,7					311.9		
<del></del>	944.3		5,307.2		350.0		123.4	15.0	38.9		18,511.9
	93.0 64.9	613.9	20,773.2 3,040.0	35.4	350.0		561.2	1,200.0	923.9	<del> </del>	33,973.2
<del>-+</del>	04.9	T					9.4	60.0		<del> </del>	6,134.5
<del></del>		11.9	231.6		355.5		127.7	136.4	791.1		3,971.3
		1			653.7		26.5	1,905.0	2,771.3	<del> </del>	12,296.6
	506.2	957.5	5,749.7	7.0			401.7	69.5	76.6		12,283.2
<del>-</del>	213.9	1,065.8	2,154.9		728.3	· · · · · · · · · · · · · · · · · · ·	253.9	141.3	164.2		6,611.3
<del></del>	1.822.3	5,090.3	43,359.9	4,101.1	2,855.2		1,549.2	4,117.0	5,119.1	<del> </del>	107,609.3
	125.8		2,046.1		<del> </del>	<del></del>	197.3	81.8	157.2		3,447.6
<del></del>	32.9	1	5,476.1				45.0	701.9	677.9	-	7.322.9
<del></del>		2,405.1				:					2,405.1
1			5 <b>,</b> 477.5						ļ	<del> </del>	5,477.5
7 12,374.5 6,944.1	2,009.6	7,817.8	136,927.0	14,704.5	12,631.2	6,805.6	1,807.5	19,755.2	18,563,4	13,949.9	347,220.6
.7	7 12,374.5 6,944.1	7 12,374.5 6,944.1 2,009.6	7 12,374.5 6,944.1 2,009.6 7,817.8	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0 14,704.5	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0 14,704.5 12,631.2	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0 14,704.5 12,631.2 6,805.6	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0 14,704.5 12,631.2 6,805.6 1,807.5	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0 14,704.5 12,631.2 6,805.6 1,807.5 19,755.2	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0 14,704.5 12,631.2 6,805.6 1,807.5 19,755.2 18,563.4	7 12,374.5 6,944.1 2,009.6 7,817.8 136,927.0 14,704.5 12,631.2 6,805.6 1,807.5 19,755.2 18,563.4 13,949.9

that most of the development costs are contained in the logistics configuration cost estimate.

The assumption that these two stages are identical results in cost reductions which are appreciably greater than those achievable if it is assumed that only the modules are identical. In this configuration, however, these reductions are offset by the requirement for an additional stage.

## 4.5.1 Static Test

In the development static test program for this configuration it is considered unnecessary to conduct any appreciable number of static firings on L-I and L-II. On this basis it has been planned to utilize flight articles for this minor amount of testing, thereby eliminating any requirement for special static test articles for these two stages. The third stage, however, is new and must be developed; and since it is modular, it was planned to utilize the module contractor's static firing facility for module development. For development firing of the complete stage, the dual stand already in existence for the logistic program can be utilized, provided it is modified to supply a capability for testing the third stage. It appears that this facility will then be adequate to support both programs from a schedule standpoint.

## 4.5.2 Development Flight Testing

In spite of the fact that the flight test program for this configuration requires provisions for testing a manned third stage, it has been planned with fewer flights than any of the two stage configuration programs. This planning was made feasible by the assumption that stages L-I and L-II have been developed and flight tested in the modular logistics program.

The program (Table 4-1) is initiated with two Little Joe lob-shot flight tests which include all three stages and a semi-complete Apollo Command Module. The latter would consist essentially of the structure and whatever elements of the guidance, attitude control, communications, and thermal control systems are necessary for the tests. Although this first test vehicle contains all three stages and is therefore quite expensive, it is estimated that a program which includes dynamically suitable dummies as well as an interim attitude control system, etc., would also be expensive. In addition, it would provide less applicable test information and would run the risk of failures due to the complex interim equipment. Based on these considerations it was planned to use the actual configuration hardware.

The program also includes two earth orbital flights, one manned and one unmanned. In the case of logistics vehicles it was concluded that orbital tests, because of their expense as compared with the information to be obtained, were not necessary. In the case of the manned missions, however, it was concluded that the presence of the crew changes the considerations enough to require these tests. Two tests are planned using the Saturn IB for a booster. In both tests the command module would be in its operational configuration; the first test would be unmanned and, if it is successful, the second would be manned.

## 4.5.3 Facilities

As discussed previously, one of the principal advantages of the modular pair program is the smaller number of facilities required when compared to the tailored pair. Table 4-2 indicates that the number of additional facilities required for the modular manned program is: five stage assembly sections, no additional refurbish and vertical test bays, one additional static test stand (for the third stage), no additional development flight test stand, and one additional Saturn V launch stand at AMR. In addition, one Saturn IB launch facility at AMR is needed.

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## 4.5.4 Ground Support Equipment (GSE)

The GSE required for this program is that necessary to support the additional facilities described in the previous section. Very little additional design and development will be needed, the bulk of the costs being those necessary to provide equipment and modifications for the additional stage.

## 4.5.5 Configuration

The modular manned configuration (Figure 2-4) is a three-stage configuration. It utilizes the module in each stage, however, the entire L-I and L-II stages are identical, which tends to overshadow the modular effects. In this situation there are very minor development costs for these two stages, only those necessary to rearrange some of the subsystem equipment; fabrication costs are of similar magnitude. The module development costs for the third stage are estimated to be approximately 20 percent of the original module development costs. This vehicle requires extremely large landing gear for the L-II stage as did the modular logistics configuration.

For the manned configurations it is assumed that portions of the guidance, attitude control, and thermal control systems from the command module can be utilized for the entire vehicle. These costs have been deducted in the estimates presented, and since the command module costs are not included in the estimates, the net result is a cost decrease. In all cases, the systems and integration engineering costs have been retained since such an arrangement will require appreciable interface effort.

This configuration will also require large attitude control engines in the return stage since the main engines are located very close to the center of gravity. The costs estimated for these engines will be conservatively low if a development program is required for these engines.

## 4.6 TAILORED PAIR, LOGISTIC AND MANNED SPACECRAFT COSTS

Table 4-9 is a cost matrix for the tailored manned configuration program. The costs of this matrix when combined with those of the tailored logistics configuration (Section 4.4) comprise the second lunar direct flight pair. This program is essentially a duplicate of the tailored logistics program requiring duplicate facilities and operations. No commonality of operations or hardware was assumed in this estimate, primarily because at the time the program plan and cost estimates were initiated the configurations were not similar. The configurations shown (Figures 2-1 and 2-2) are similar enough that some commonality could undoubtedly be achieved with additional design effort.

#### 4.6.1 Static Test

The static test program is that required to develop two propulsion systems. Although both systems utilize the same type of engines, there are two in the L-I stage and one in the L-II stage. The systems are sufficiently different so that extensive development effort would be required. As a result two dual stands and a two-stage static test vehicle are planned (Table 4-2).

#### 4.6.2 Development Flight Testing

The first five flights of the development flight program are similar to the five flights of the tailored logistics program except that now the return stage and command module must be either included or simulated. The program as planned (Table 3-2) provides four L-I propulsion tests, three L-II propulsion system tests and three guidance flights. Upon completion of these tests, two earth orbital flight tests are planned to provide "space-soak" and other tests. These tests bring the L-I propulsion system tests to six, L-II propulsion to five, guidance to five and two tests of the command module, one manned, the other unmanned.

					Table 4	1-9. Tailore	ed Manned C	onfiguration	Program C	ost Matrix									
		<del>1</del>	Ţ <u></u>	ENGINE	EERING	- <sub>1</sub>				TOOI	LING AND M	ANUFACTU	RING			TEST AND	OPERATION	S.	
Stage/Subsystem/Item	Program Mgmt	System Engr	Analysis and Design	Dev Testing	Specifi- cations	Engr Data and Reports	Reliability	Quality Assurance	Tooling Design	Tooling Fabrication	Production Fabrication	Spacecraft Assembly	Spacecraft Accep. Test	Quality Control	Qualifica- tion Test	Offsite Test	Launch Operations	Logistics	TOTAL
Spacecraft	29, 318. 5	10, 055.4	1,054.3	2,173.6	404.0	6, 646, 5	16, 175, 5	7,907.1				2,737.1	8,069.2	7,749.3	42.8	15, 364, 9	10,238.6	15 994 3	133, 821. 1
Mockup		25.9	175.8					1.701.1			43.2		3,00/.2	,	10.0	13,301.7	10,230.0	15,004.5	244.9
L-II Stage		2,508.0		210.2	L							5, 515. 3	1,477.1		45.4	629.1	311.9		10,697.0
Structure		<u> </u>	6,731.3	3,528.2					944.3	2, 312, 2	7,902.6			· · · · · · · · · · · · · · · · · · ·	123.4	16.0			21,596.9
Propulsion		<u> </u>	4, 843. 3	2,999.4			·		150.8	355.0	12,991.9	13.8	168.0		1,090.9	962.8			23, 934, 8
Thermal Control			2,800.0	650.0					64.9	129.0	2,736.0				7.7	50.9	1		6, 438.
Attitude Control	· · · · · · · · · · · · · · · · · · ·	<u> </u>	1,552.1	565.0					73.7	295.5	254.8		355.5	<del></del>	136.2	136.4	791.1		4, 160. 3
Guidance System			7, 175. 4	3,508.6					43.2	649.9	3, 221.1		898.9		26.5	2,177.2	2,771.3	<b></b>	20, 472.
Electrical Power			2,637,4	1, 109. 9			1		506.2	957.5	5, 174. 9	7.7	839.1		346.7	79.5	76.6		11,735.5
Communications & Telemetry		1	1,598.7	290.3			1		213.9	1,065.8	2, 154. 9		728.3		253, 9	150.8			6,620.9
Total L-II Stage		2,508.0	27, 338.2	12,861.6					1,997.0	5, 764, 9	34, 436. 2	5, 536, 8	4, 466. 9		2,030.7				
L-I Stage		1, 392.7		70.0					1, 771.0	3, 104, 7	34, 430. 2	3,649.6	4,400.9		2,030.7	4, 202. 7			105, 656. 0 5, 361. 1
Structure			7,504.9	6, 155. 3			<del></del>		1 735 9	4 111 6	24, 226. 4	3,047.0			81.2	15.0	·	<del>                                     </del>	43, 859.
Propulsion			7,562.1	5, 287.4			7,1		1,094.3		22,966.6	44.5	562.1		3,035.2	1,777.4		<del> </del>	47,041.
Thermal Control			2,200.0	1,400.0					353.0	377.7	1, 188. 9	11.5	302.1		9.4	22, 3	<del></del>		5, 551.
Guidance System			2,224.2	1,614.5		<u> </u>	<del> </del>		62.8		2,023.6		176.7		15.6	22.3	<del> </del>		6,731.
Electrical Power			177.2	114.3		,			108.0	115.5	3, 535. 3		189.6		79.8	<del></del>			4, 319.7
Total L-I Stage		1,392.7	19,668.4	14,641.5			· · · · · · · · · · · · · · · · · · ·		3, 354. 0		53, 940. 8	3, 694. 1	928.4		3,221.2	1,855.6	1, 337.1		112, 864.
Mechanical GSE		174.3	86.0	37.7			<del> </del>		3, 334. 0	6, 630.8	53, 940. 6	3,094.1	920.4		3,221.2	<del></del>	<del>                                     </del>	<del> </del>	
L-II Stage			2,771,6	385,4	<del></del>	<u> </u>	<del></del>		105.0							81.8	157.2		537.0
L-I Stage			3,033.4	547.4		<del></del>	<del></del>		125.8		2.046.1		<del> </del>		197.3		<del> </del>		5, 702.
Electrical GSE		118.3	5,285.0	2,032.9		<del></del>			131.0 328.7	212.3	5.163.2				253.0		/		9, 340.
Electrical Special Test Equipment			889.8	2,032.7			ļ — — — — —		348.1	462.7	19,738.8				<b></b>	701.9	677.9		29, 346. 2
Facilities			507.0							24,051.4	12 15/ 0								24, 941.2
											13, 156, 0	<del></del>							13, 156. (
TOTAL	29, 318, 5	14,274.6	60, 302, 5	32,680.1	404.0	6,646.5	16, 175, 5	7, 907, 1	5, 936, 5	39, 498, 4	128, 524, 3	11,968.0	13, 464, 5	7,749.3	5,745.0	22, 206, 9	16, 923. 8	15, 884, 3	435, 609, 8
		ļ																	
•		1				<del> </del>			<u> </u>		ļ				<b> </b>		ļ ·		
	•	<del> </del>	t	-		<del> </del>	<del></del>				<del> </del>	<del></del>			<b>-</b>		<del> </del>		
		1					<del> </del>		L		ļ		ļ		<b> </b>			ļ	
			1			+	<del> </del>		<u> </u>	<del> </del>	<del> </del>								
		<del> </del>	<del> </del>			<del> </del>	<del> </del>	L							ļ		ļ	ļ	ļ
		†	<del> </del>	-		<del> </del>	-		·						<b>_</b>		ļ	<b> </b>	
			<u> </u>			<del> </del>	<del> </del>				<del> </del>				ļ		<b> </b>		
	····-	<del>                                     </del>	<u> </u>			-	ļ				ļ			···	ļ,		<del> </del>	ļ <u>.</u>	
	· · · · · · · · · · · · · · · · · · ·	1		l		ł		<u></u>		L					<u>.                                    </u>		<u> </u>	L	L

#### 4.6.3 Facilities

The facility requirements, summarized in Table 4-2 are essentially duplicates of the tailored logistics program requirements. This results in double requirements when the system is considered as a pair being developed concurrently.

## 4.6.4 Ground Support Equipment (GSE)

The GSE requirements are those necessary to support the duplicate facilities. Although it may be possible to utilize some of the tailored logistic L-I stage equipment design, very little of the L-II stage equipment would be applicable due to the configuration differences especially in the propulsion area. No allowances for the use of common equipment have been included in this estimate.

## 4.6.5 Configuration

The tailored manned configuration (Figure 2-2) is a two-stage vehicle utilizing two RL-10 engines in the L-I stage and a single RL-10 engine in the L-II or return stage. Attitude control of the L-II stage is provided by a reaction jet system. The crew is located in an Apollo command module which forms the nose of the vehicle. As in the case of the modular manned configuration it is assumed that certain elements of the guidance, attitude control, and thermal control systems, which are part of the Apollo system, can be utilized for the complete vehicle.

# 4.7 MODULAR AND TAILORED PAIR COSTS USING NASA (MSFC) FLIGHT TEST PROGRAM

The foregoing cost estimates on the modular and tailored configurations were based upon the flight test programs summarized in Table 4-1. These programs utilized Little Joe boost vehicles for lobshot flights except for two tests of each manned configuration which use Saturn IB boost vehicles. During the presentation at MSFC on November 12, it was pointed out that there is a school of thought within NASA which feels that the lob-shot technique is inadequate and that the test

Table 4-10. Flight Test Program - Modular and Tailored Pairs Using Saturn Launch Vehicles

	Manned	•	ı		t	1					o N	oN O	Yes	Yes
	Apollo	•	•		1	•	•				Semi-Live	Semi-Live	Live	Live
	Guidance	Yes	Yes		Yes	Yes	Yes				Yes	se X	Yes	Yes
Modular	L-III	(	ı			ı	ı				Live	Live	Live	Live
	L-II	Dummy	Live		Live	Live	Live				Dummy	Live	Dummy	Live
	L-I	Live	Dummy		Live	Live	Live				Dummy	Live	Dummy	Live
	Manned	ı	•	ı	•	1	ı	No	No	o N	No	o N	Yes	Yes
	Apollo	ı	ı	ı		ı		Dummy	Dummy	Dummy	Semi~Live	Semi-Live	Live	Live
Tailored	Guidance	Yes	Yes	Yes	Yes	Yes	Yes							
	п-п	Dummy	Dummy	Live	Live	Live	Live	Dummy	Dummy	Live	Live	Live	Live	Live
	L-1	Live	Live	Dummy	Dummy	Live	Live	Live	Live	Dummy	Dummy	Live	Dummy	Live
Booster		Saturn IB	Saturn IB	Saturn IB	Saturn IB	Saturn IB	Saturn V							
Mission				IC	TSIOC	г			<u></u> 9;		NNED	ΑM		

program will require at least Saturn IB boosters plus, for the manned configurations, at least one Saturn V boosted flight prior to a lunar flight.

Consequently, it was requested by MSFC that a cost estimate of a program utilizing these boosters be prepared. MSFC provided the flight test programs shown in Table 4-10 to be used for estimating purposes. This program was prepared using as a ground rule the fact that the same number of test flights should be made and that any changes in the number of test vehicles required should be minimized.

Using these test programs, the estimates of Sections 4.2, 4.4, 4.5 and 4.6 were modified to take into account the new booster costs as well as the test vehicle configuration changes. It was assumed that the test support costs for the upper stages would remain nearly the same although they would undoubtedly increase with the larger boosters.

The results of this analysis are indicated in Table 4-11.

Table 4-11. Modular and Tailored Pair Cost Summary (\$\x 10^6\$),
MSFC Flight Test Program Using Saturn Boosters

Configuration	Original Cost With Little Joe Boosters	Cost With Saturn Boosters
Tailored Logistics	480.3	647.3
Tailored Manned	435.6	708.6
Modular Logistics	478.9	625.5
Modular Manned	347, 2	527.7

The effects of this test program are to increase the total program costs appreciably and to increase the cost advantages which are obtained through the application of the modular concept. The latter effect is the result of the decreased flight test requirements when the propulsion system is essentially already developed and qualified.

#### 4.8 HYBRID PAIR

The analyses of the modular pair indicated the possibility that an improved modular configuration could be designed which would provide the cost advantage of the modular concept without incurring other penalties which offset these advantages. The hybrid pair is an attempt to accomplish this. As stated previously the programs for these configurations were not planned in the detail of the other two pairs and therefore are not described in such detail in this section.

## 4.8.1 Hybrid Logistics

This configuration (Figure 2-5) utilizes the tailored L-II stage of the tailored logistics configuration (Figure 2-5) and a modular L-I stage. The L-I stage is appreciably larger than the L-I stage of the modular logistics configuration and the propellant tanks are much longer. Table 4-12 is a cost matrix for this configuration. The vehicle requirements for this configuration (Table 4-4) are identical to those of the tailored logistics program as is the flight test program (Table 4-1). This follows from the fact that in this program, as in the tailored program, it is necessary to develop and qualify two propulsion systems.

#### 4.8.2 Hybrid Manned

This configuration (Figure 2-6) utilizes the tailored L-II stage of the tailored manned configuration (Figure 2-2) and the modular L-I stage. In this case the module is the only common equipment in this stage; the remainder of the stage is considered unique.

Table 4-13 is a cost matrix for this configuration. Inasmuch as only one stage is modular, the vehicle and facility requirements are not reduced to the extent of the modular manned configuration. Conversely, there is no third stage with its subsequent expenses. These factors are summarized in Table 4-1 through 4-4. In this configuration it is estimated that less than 1 percent of the original modular development cost would have to be expended for this configuration.

Table 4-12. Hybrid Logistics Configuration Program Cost Matrix

	<u>                                     </u>	T	· · · · · · · · · · · · · · · · · · ·	ENGINE	ERING	<b>~~</b>			,	100I	ING AND M	ANUFACTU	RING			EST AND C	PERATIONS	5	
Stage/Subsystem/Item	Program Mgmt	System Engr	Analysis and Design	Dev Testing	Specifi- cations	Engr Data and Reports	Reliability	Quality -	Tooling Design	Tooling Fabrication	Production Fabrication	Spacecraft Assembly	Spacecraft Accep. Test	Quality Control	Qualifica- tion Test	Offsite Test	Launch Operations	Logistics	TOTAL
Spacecraft	30,843.1		1,054.3	2,173.6	480.3	6, 992, 1	17,016.7	8.491 0				2,737.1	8,069.2	8,321.5	42.8		<del> </del>	17,057.2	
Mockup		25.9	175.8			3,,,-1	21,020.1				43,2		0,007.5	0,32113	121.0.	<del> </del>	ļ	11,031.2	<del>                                     </del>
L-II Stage				210.2				i				6,741.2	1,342.8		45.4		1		
Structure		T	6,731.3	3,528.2					944.3	2,312.2	7,184.2	-,,,,-			123,4	t	<del> </del>		<b></b>
Propulsion			3,653.0	2,424.7					150.8	451.4	8,094.1	13.8	168.0		1,341.6				
Thermal Control			2,451.3	540.0					64.9	129.0		13.0	100. 9		9.4		<del> </del>		l
Attitude Control			1,776.6	579.6		1			73.7	338.4			200.0		149.3	<del> </del>	<del> </del>		<del> </del>
Guidance System			19,042.6	22,125.9				- <del>-</del>	43, 2			227 E			1	<del> </del>			<u> </u>
Electrical Power			2,637.4	1,109.9	-			· · · · · · · · ·	506.2	957.5	12,764.5 5,749.7	237.5 7.7	898.9 839.1	<del></del>	43.5		<del> </del>		
Communications and Telemetry			2,104.1	363.5					213.9	1,076.1			728.3		318.6		· · · · · · · · · · · · · · · · · · ·		<b></b>
Total L-II			38,396.3	30,882.0					1,997.0			7,000.2	4,177.1	<del></del>	2,432.9	<del> </del>	•		<del></del>
L-I Stage	***************************************	· · · · · · · · · · · · · · · · · · ·	30,370.3	30,002.0				<del></del>	1,991.0	5,914.5	45,109.8	3,345.5	4,1(1.2		2,432.9				<del></del>
Structure			7,504.9	6,155.3			-	+	1,531.1	2 626 4	19,425.1	3,343.3			<del> </del>	<del> </del>	<del> </del>		<del></del>
Propulsion			9,069.1	5,744.2		<del> </del>		+	1,094.3		24, 227. 0	40.3	432.4		2,626.4	<del> </del>			
Thermal Control		<u> </u>	2,398.6	1,929.5				1				40.3		<del></del>	2,020.4	<del> </del>	<del> </del>		<del>                                     </del>
Guidance System			2,224.2	1,614.5		ļ	<del></del>	+	353.0 62.8	614.5	1,188.9 2,023.6		176. 7 176. 7		<del> </del>	<b> </b>	<u> </u>		
Electrical Power			177.2	114.3				- <del> </del> -	108.0			<del>-</del>		<del></del>	<del> </del>	<u> </u>	<b> </b>		<del></del>
Mechanical GSE		1	78.9	34.6				<del></del>	108.0	113.3	3,535.3		189.6		<del> </del>		<del> </del>		<b></b>
L-I		1	2,542.7	353.5					125.0	17/ 0	2 04/ 1				107.0		<del>  `</del>		ł
L-II			2,782.8	502.2				<del></del>	125.8		2,046.1				197.3 253.0	<b></b>	<del> </del>		<b></b>
Electrical GSE		† <del></del>	5,285.0	2,032.9				+	131.0		5, 163.2				453.0		<del> </del>		<b></b>
Special Test Equipment			3,203.0	889.8					328.7		20,216.9				<del> </del>	<del> </del>	<del> </del>		<del> </del>
Facilities	<del></del>	<del> </del>	t	007.0	<del></del>			· <del></del>		4,000.0	20,051.4				<b>+</b>				
		†	†		<del></del>	<del>   </del>					12,907.5				<del> </del>	<del> </del>	<u> </u>	<del>-</del>	<del> </del>
TOTAL	30,843.1	14,300.4	71,689.8	52,426.4	480.3	6,992.1	17,016.7	8,491.0	5,731.7	19,208.9	155,938.0	13,123.1	13, 221. 7	8,321.5	5,552.4	22,959.0	16,747.6	17.057.2	480.100
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															†	1	<u> </u>		<b></b>
															<b>†</b>		<del>                                     </del>	<del>                                     </del>	t

Table 4-13. Hybrid Manned Configuration Program Cost Matrix

				ENGINE	ERING						TOOL	ING AND M	ANUFACTU	RING			TEST AND	OPERATION	ıs	
Stage/Subsystem/Item	Program Mgmt	System Engr	Analysis and Design	Dev Testing	Specifi- cations	Engr Data and Reports	Reliabil	ity As	Quality ssurance	Tooling Design	Tooling Fabrication	Production Fabrication	Spacecraft Assembly	Spacecraft Accep. Test	Quality Control	Qualifica- tion Test	Offsite Test	Launch Operations	Logistics	TOTAL
Spacecraft	23,483.0		1,054.3	2,173.6	350.3	5,201.6	12,65		6,161.9				2,455.0	7, 269.0	6,038.9	39.6				
Mockup		25.9	175.8									43.2								
L-II Stage				210.2									5,515.3	1,477.1		45.4				l
Structure			6,731.3	3,528.2						944.3	2,312.2	7,902.6				123.4				
Propulsion .			4,843.3	2,999.4						150.8	355.0	12,991.9	13.8	168.0		1,090.9				·
Thermal Control			2,800.0	650.0						64,9	129.0	i				7.7				
Attitude Control			1,552.1	565.0						73.7	295.5			355.5		136.2				
Guidance System			7,175.4	3,508.6			,			43.2	649.9			898.9		26.5			1	
Electrical Power			2,637.4							506.2	957.5				-	346.7				
Communications and Telemetry			1,598.7	290.3						213.9	1,065.8			728.3		253.9		1 .	1	
Total L-II			27, 338. 2	12,861.6					t	1,997.0		34,436.2				2,030.7				
L-I Stage				70.0									2,745.5							
Structure			7,504.9	6,155.3						1,735.9	4.111.6	16,348.8				81.2	1			
Propulsion			31.5							1.1		18,295.8		395.0		260.0				
Thermal Control			2,200.0	1,400.0						353.0	377.0		<del> </del>			9.4				
Guidance System			2,224.2	1,614.5						62.8	614.5			144.6		15.6				
Electrical Power			177.2	114.3						108.0	115.5			155.1		79.8			1	1
Total L-I																				
Total GSE			10,689.4	2,923.2		Ţ, ·			1	585.5	851.3	35, 272,3							1	
Special Test Equipment			889.8	-1/23.2		1					4,000.0						i			
Facilities									, 2			9,620.0				<b>_</b>				
TOTAL	23,483.0	13,200.0	52,285.3	27,334.0	350.3	5,201.6	12,659	9.8	6,161.9	4,843.3	15,935.8	119,537.2	10,774.3	13, 157. 5	6,038.9	2,966.6	20,940.	5 16,747.	6 12,378.4	363,996
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# 4.8.3 Hybrid Pair Costs Assuming L-I Stage Commonality

The similarity between the L-I stages of the Hybrid Pair suggests the possibility of designing a single common stage for use on the two vehicles. The commonality thus achieved would reduce the costs in Table 4-13 appreciably since in those costs only the modules are considered common.

An estimate of the cost reduction which could be achieved assuming complete commonality of the L-I stage indicates that the hybrid manned program cost could be reduced approximately \$44 million, to a total of \$320 million. This figure includes reduction in structural development, testing, tooling design, and tooling fabrication as well as elimination of hardware previously required for test purposes. Reductions in costs of GSE and facility development and fabrication, program management qualification testing, quality control, logistics and off-site testing are also included. No reductions in subsystem development requirements are included in this estimate.

## 4. 9 SINGLE STAGE LOGISTICS PROGRAM

One of the more promising tailored configurations from a design standpoint is the single-stage logistics configuration which accomplishes the logistics mission with some decrease in payload. In order to properly evaluate this configuration a cost estimate was prepared (Table 4-14). As indicated in Tables 4-1 through 4-14 the development of a single-stage vehicle requires fewer test vehicles and facilities. Although it is a single-stage vehicle, it has a relatively high structural weight and requires three RL-10 engines. Thus the fabrication costs are relatively high but the reductions in the remainder of the program result in a total development cost appreciably lower than that of any of the other logistics vehicles.

Table 4-14. Single-Stage Logistics Configuration Program Cost Matrix

			·	ENGINE	ERING					TOO	LING AND M	ANUFACT	URING		1	TEST AND C	PERATION	5	
Stage/Subsystem/Item	Program Mgmt	System Engr	Analysis and Design	Dev Testing	Specifi- cations	Engr Data	Reliability	Quality Assurance	Tooling Design	Tooling Fabrication	Production Fabrication	Spacecraft Assembly	Spacecraft Accep. Test	Quality Control	Qualifica- tion Test	Offsite Test	Launch Operations	Logistics	TOTAL
Spacecraft		8,226.5	527.1 117.2	1, 081. 6								8, L30.0	7,143.7		<u> </u>	11,362.9	12,120.0		<del>                                     </del>
Mockup		25.9	117.2							30.1									
Stage															T				
Structure			10,483.8	6,605.7					2,603.8	6,167.4	36,661.0							-	
Propulsion			11,695.9	7,563.0					2,331.6		28, 183. 6				1 .				
Thermal Control			4,851.6	2,606.2		†		<u> </u>	239.5	317.8			<del> </del>	ļ — ——————————————————————————————————	<u> </u>				
Attitude Control			1,332.4	434.7		1		<del> </del>	73.7	338 4	5,262.1		<del> </del>	<del> </del>	<u> </u>	ļ	<b>†</b>		l
Guidance System			22, 166.8	23,740.4		1		† · · · · · · · · · · · · · · · · · · ·	136.5				<del> </del>		†				<b></b>
Electrical Power			2,696.4	1,147.0		<del> </del>			78.8		7,524.7		<del> </del>	<del> </del>	+				<del> </del>
Communications and Telemetry			2, 104.1	363.5				<u> </u>	213.9				+	ļ	<del></del>				·
Mechanical GSE ·			3,470.4	520.9		1	<u> </u>	<u> </u>	169.5	246.8			<del> </del>	·	t		<del> </del>		<del></del>
Electrical GSE			4,756.5	1,829.6		<del> </del>		<del> </del>	295.8				<del> </del>		· <del>                                     </del>		<del> </del>		<del></del>
Special Test Equipment			1						273.0	4,000.0			+		<del> </del>		<del> </del>		<del></del>
Facilities										1,000.0	9,050.0					7			
TOTAL	27,202.7	8,252.4	64, 202.2	45,892.6	434.5	6,902.2	14,775.0	7,042.9	6,143.1	19,402.2	149,378.8	8,130.0	7,143.7	7,042.9	4,189.3	15,362.9	12,120.0	14,148.2	419,700.
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This configuration can be combined with the tailored manned configuration to form a tailored direct flight pair. From a cost standpoint, if it is desired to combine it with the modular or hybrid manned configurations, the costs presented for the latter configurations must be modified inasmuch as they are based on the assumption that the module development costs are paid under the corresponding logistics program. Hence, if the logistics program is not accomplished, the manned systems must include the module development costs.

Nevertheless, the single-stage configuration has many desirable features, including low costs, and is indicative of the improvements which may be obtained through design.

#### 4.10 HYBRID B MANNED CONFIGURATION

The modular manned configuration discussed in section 4.5 had several disadvantages which included both high costs and low performance. Another modular configuration, which provides somewhat better performance, was designed in an effort to improve this situation. This configuration, called "hybrid B manned" to distinguish it from the other hybrid manned configuration, consists of the same L-I and L-II stages as the modular logistics configuration; therefore, complete commonality has been assumed between these stages (not extended to subsystems). The L-III stage is similar to the L-II stage of the tailored manned configuration except for the landing gear which in this case is attached to the L-II stage.

As indicated in the summary of the program plan for this vehicle (Tables 4-1 through 4-4), this vehicle requires more additional facilities than the modular manned configuration because it is now necessary to develop another stage. Since the L-I and L-II stages have already been developed, it is not necessary to provide static or engineering integration test items for these stages but it is necessary to provide an L-III stage article for each of these purposes. It is also necessary

to provide an additional static test stand for testing the L-III stage with its new propulsion system.

The flight test program is initiated with the test of the complete vehicle since the first two stages will have already been developed in the modular logistics program. Considering the difficulty of constructing two dummy stages (L-I and L-II) for testing the L-III stage alone, it was decided that the program should be initiated with a test of the complete vehicle.

For this configuration the development cost, including four operational vehicles, was estimated to be \$348.4 million. No cost matrix is presented for this configuration, however, the costs are included in the summary cost information in the next section. The cost of this program is very similar to the modular manned program, therefore, any improvement as a result of this design has to be reflected in performance only.

#### 4.11 EXPERIENCE CURVE APPLICATION

The cost data presented in the matrixes do not include the reductions in fabrication costs which occur as additional vehicles are constructed and additional experience and learning are obtained. In order to take this factor into account a 90 percent experience or learning curve has been applied to the matrix costs. It has been assumed that the effects of this learning or experience is initiated after the first five vehicles (including test articles) have been built and tested and the test results have been incorporated into the design.

In applying this curve, the costs of materials have been deducted from the vehicle recurring costs before the curve has been applied.

In the case of the modular configurations the learning curve has been applied to the modules separately in order to take advantage of the greater reductions in unit costs due to the greater number of modules constructed. This latter effect is illustrated by the modular pair. Although only nine logistics vehicles and eight manned vehicles (excluding odd stages) are constructed in the program up until the time four operational vehicles of the respective types have been completed, 42 modules will have been constructed. By applying the learning curve to this major subsytem separately, after the first five modules have been constructed, an appreciable cost reduction is realized which reduces the modular configuration costs even further.

Section 5.7 contains the summary cost information which includes the effects of the experience curves.

#### 5. DISCUSSION OF RESULTS

#### 5.1 MODULAR PAIR

Examination of the costs of the configurations comprising this pair indicates that the manned program costs approximately \$131 million less than the logistics program. In estimating the costs of this pair three assumptions were made which are the principal reasons for this differential:

- a) All costs of developing the module are charged against the logistics configuration L-I stage, hence, the only module development costs for the L-II stage are those required to adapt the module to the new tank lengths. It is assumed that identical modules are used in the L-I and L-II stages of both the logistics and manned configurations, therefore, the only module development costs in the manned configuration are those required to adapt the module to the L-III stage.
- b) It is assumed that not only the module but the entire L-I and L-II stages are identical between the two configurations, with the exception of certain subsystem arrangements. This eliminates a large increment of development costs in addition to those saved through the use of the module.
- c) The third assumption causing the price decrease is that certain elements of the guidance, thermal control and attitude control system which are in the Apollo command module will be utilized for the manned system. The system integration costs are retained but the development costs of these components are eliminated.

The foregoing assumptions complicate the task of determining the savings which are attributable to the module, however, it is estimated that the latter amount is about \$65 million. This includes both spacecraft and GSE components development and test, qualification, etc. It also includes reduced GSE and facility hardware requirements.

It is of interest to note that the extra stage and engines required for the manned vehicle more than offset the hardware savings due to the reduction in vehicle requirements which comes about as a result of the use of the module. This suggests the possibility of an improved modular design and was one of the factors which lead to investigation of the hybrid pair.

#### 5.2 TAILORED PAIR

The tailored logistics configuration is similar to the LLS C-5 configuration of Reference 3-1 and the cost estimates are very similar. The differences which do exist are because:

- a) The engines of both stages are now at a later stage of development than they were at the time of the LLS estimate. As a result, certain engine development costs were eliminated.
- b) Both facility (brick and mortar) and Little Joe launch vehicle costs are included in the present estimates and were not included in LLS.
- c) A landing gear replaces the landing pads used in LLS.
- d) One less L-II stage is flight tested than was planned in LLS program.

Cost differences between the tailored manned and tailored logistics configuration are due principally to the fact that certain parts of the guidance, attitude control and thermal control system are considered to be provided as a part of the Apollo command module, hence, are not included in this cost estimate as was also the case with the modular manned configuration.

#### 5.3 MODULAR VERSUS TAILORED PAIR

The cost differential between the modular logistics and the tailored logistics programs is very small, the modular being approximately \$1.4 million lower. In the case of manned programs, however, the modular program is approximately \$88 million less than the tailored. An immediate conclusion, which tends to be drawn, is that the modular approach is responsible for this difference. Analysis of the cost differences indicate that the modular approach is indeed responsible for about \$60 million of

this difference, however, another major factor is the complete commonality of the L-I and L-II stages of the modular manned and logistics configurations. Based on this assumption, the modular manned estimate contains no development, tooling, or qualification costs for the structure of this configuration.

It is significant to note, as was mentioned in discussing the modular pair, that the additional stage and engines required by the three-stage modular manned vehicle more than offset the effect of the reduction in total vehicles required, made possible through the modular concept. This factor is even more clearly demonstrated by the difference in recurring costs for the two vehicles, \$21.3 million for the modular manned as compared with \$15.4 million for the tailored manned. This result emphasizes the possibility of advantages to be obtained through design of improved modular configurations.

#### 5.4 HYBRID PAIR

The costs of the hybrid pair indicate a difference between the manned and the logistics programs of approximately \$116 million, the manned being lower. As in the case of the other pairs, the costs of the module development are all assumed to be paid in the logistics program, thus any savings show up in the manned program. Unlike the modular pair programs, no commonality other than that of the module was assumed in estimating this pair. However, use of certain Apollo subsystem elements was again assumed for the manned configuration. Only the L-I stage is modular in this pair; the other two stages are considered to be tailored and to have the same costs as the L-II stages of the corresponding stages of the tailored vehicles. These costs vary with the number of stages required however.

Analysis of the costs indicates that the modular concept is responsible for approximately \$65 million of the above difference, the remainder of the difference being the result of cost differences between the L-II

stages and the use of Apollo subsystems. It is interesting to note that the \$65 million is more than the \$60 million decrement attributed to the modular concept in the modular pair even though the latter utilized the module in three stages and the present configuration utilizes it in only one. This illustrates the fact that in the modular program many of the advantages, which the module concept makes possible, were offset by the extra stage and engine requirements of that configuration. This, in turn, emphasizes the importance of design in exploiting the modular concept to its fullest advantage.

#### 5.5 SINGLE STAGE LOGISTICS

During the design of the various vehicles, the possibility of accomplishing the logistics mission with a single-stage vehicle became apparent. Such a vehicle was designed, and due to its many advantages a cost analysis of this vehicle was prepared. In spite of the fact that the vehicle is a single-stage vehicle, the production fabrication and assembly costs were estimated to be of the same order as the other configurations due to the large structural weight and requirement for three RL-10 engines. In many other areas, however, cost savings which amount to approximately \$60 million were realized when compared with the other logistics programs. These areas include program management, system engineering, analysis and design, development testing, spacecraft assembly and acceptance, qualification testing, off-site testing and launch operations.

#### 5.6 HYBRID B MANNED

This configuration was designed in an attempt to provide a modular manned configuration with improved performance, and possibly lower cost, than the initial modular manned configuration. However, the costs, when estimated, were slightly greater than the costs of the modular manned program. This result emphasizes the fact that the requirement for a third stage results in higher costs both from a development and from a recurring cost standpoint.

#### 5.7 COST SUMMARIES

The costs discussed up to this point are the costs as presented in the matrixes which do not take into account the cost reduction made possible through experience gained as additional units are constructed. Table 5-1 is a cost summary of all the configurations investigated which does include the experience curve reductions, as explained in Section 4.11. Costs are presented for development only, for development plus four operational vehicles, plus ten operational vehicles and plus 16 operational vehicles.

In order to illustrate the relationships of these estimates, a series of summary curves are also included. Figure 5-1 shows the costs of the tailored pair (tailored logistics and tailored manned), the pair composed of hybrid B manned and modular logistics, the pair composed of the hybrid manned and the single stage logistics, the pair composed of the hybrid manned and the modular logistics, and the pair composed of the hybrid B manned and the single stage logistics.

In estimating the costs of the hybrid manned and the single stage configuration, it was estimated that an additional \$61.2 million would be required above the development cost shown in Table 5-1 because the module had not been developed previously in the hybrid logistics program as was assumed when the hybrid manned program was initially estimated. Similarly, for the hybrid B manned and single-stage pair this same cost increment was added to the hybrid B manned development cost.

In estimating the costs of the pairs composed of the hybrid manned and modular logistics configurations, an increment of \$18.2 million was added to the hybrid manned development costs. This increment was estimated as that necessary to adapt the module utilized in the modular logistics configuration to that utilized in the hybrid configuration. This same increment is applied in the case of the pair composed of the hybrid B manned and the hybrid logistics configuration.

Table 5-1. Cost Summary Including Experience Effects

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Configuration	Development Gost with 0 Operational Vehicles	Recurring Cost First Five Articles	Development Cost with 4 Operational Vehicles	Development Cost Developmen. Cost with 10 Operational with 16 Operational Vehicles	Development Cost with 16 Operational Vehicles	Remarks
Tailored Logistics	409.8	17.6	461.9	547.4	605.4	
Tailored Manned	371.1	15.4	414.6	493.4	546.9	
Modular Logistics	401.1	19.9	460.5	553.7	622.7	
Modular Manned	253.4	21.3	321.9	426.8	498.9	Assumes Module Developed under Modular Logistics Program and Commonality of L-1 and L-11 Stages
Hybrid : ogistics	410.0	17.5	461.8	545.9	0.738	
Hybrid Manned	301.1	15.3	348.3	422.4	475.6	Assumes Modulc Developed under Hybrid Logistics Program S.age Commonality not Assumed
Single Stage	356.0	16.0	403.4	486.8	537.1	
Hybrid B Mamed	261.8	21.6	336.2	431.2	565.8	Assumes Module Developed under Modular Logistics Program and Commonality of L-1 and L-11 Stages
Hybrid Manned	362.3	15.3	409.5	483.6	536.3	Assumes No Previous Module Development
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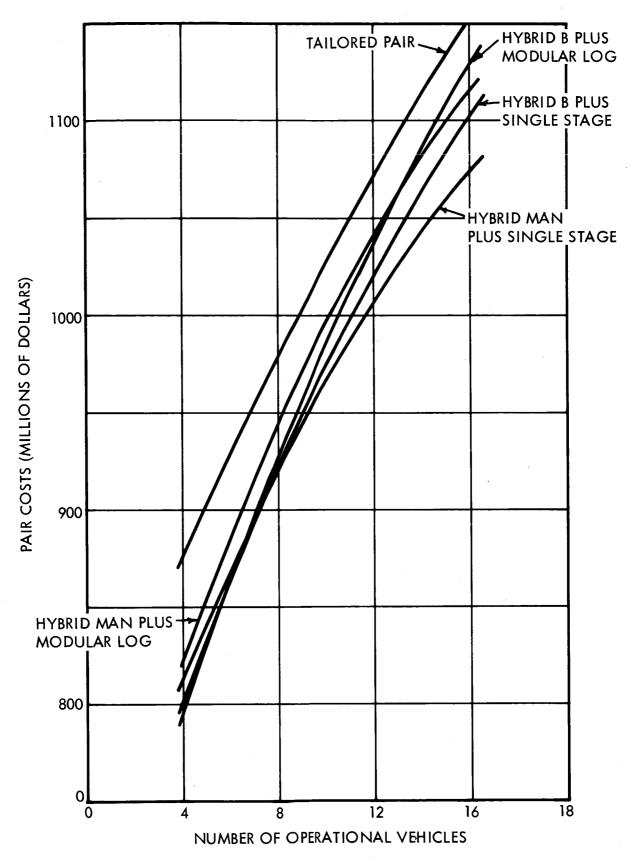


Figure 5-1. Pair Cost Summaries
Including Experience Effects

The curves in Figure 5-1 indicate that the hybrid-manned single-stage logistics pair has the lowest cost after approximately nine operational vehicles are constructed. These costs will continue to be the lowest as additional operational vehicles are constructed due to the low recurring cost of this pair.

Figure 5-2 shows the cost of additional interesting combinations. These consist of the following pairs; one pair composed of the hybrid B manned and the hybrid logistics; one pair composed of the modular manned and modular logistics (modular pair); one pair composed of the single stage and tailored manned; and one pair composed of the hybrid manned and the hybrid logistics (hybrid pair). In addition, the lowest cost pair from Figure 5-1 is shown again (hybrid manned and single stage logistics). Although several of the programs shown in this figure are not appreciably different in cost from the latter pair, it remains the lowest cost pair.

The sixth curve in this figure illustrates the cost advantages which can be obtained if the entire L-I stage of the hybrid pair is assumed to be common rather than the module only. This advantage can be seen by comparing the costs shown for the hybrid pair with and without commonality. Although stage commonality was assumed for the L-I and L-II stages of the modular pair, the overall program costs in that case tended to obscure the advantages of total stage commonality. This curve emphasizes the desirability of extending the module concept to as much of the complete stage as possible.

Figure 5-3 illustrates and emphasizes several additional major cost factors. The ordinate of this figure shows the complete cost scale beginning at zero cost, hence a better perspective of the overall cost relationships can be obtained. The top curves in this figure show the modular and tailored pair program costs with the MSFC flight test program utilizing Saturn boosters. The costs of these same pairs using the Little Joe flight test program are plotted in the center of the figure.

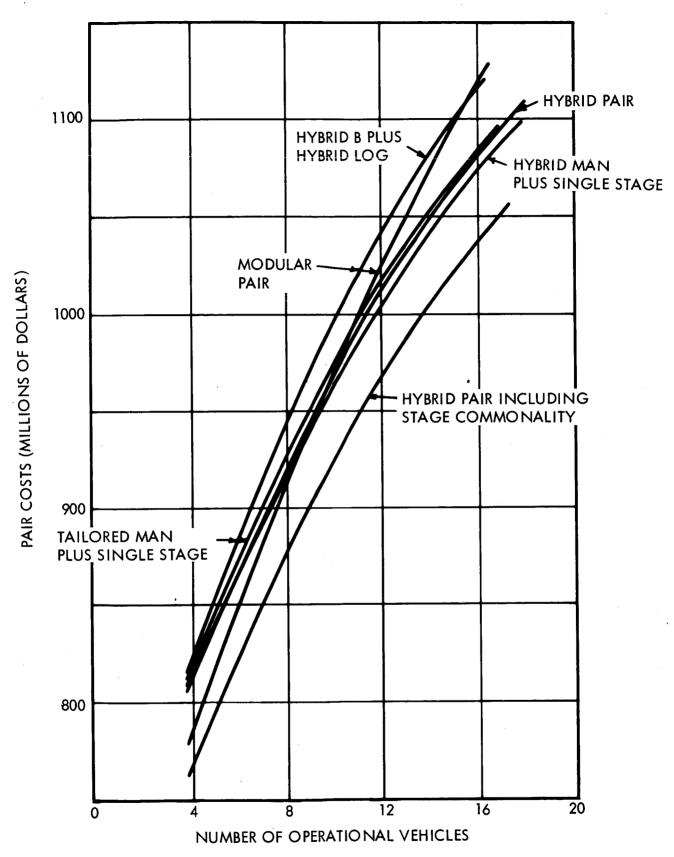


Figure 5-2. Pair Cost Summaries
Including Experience Effects

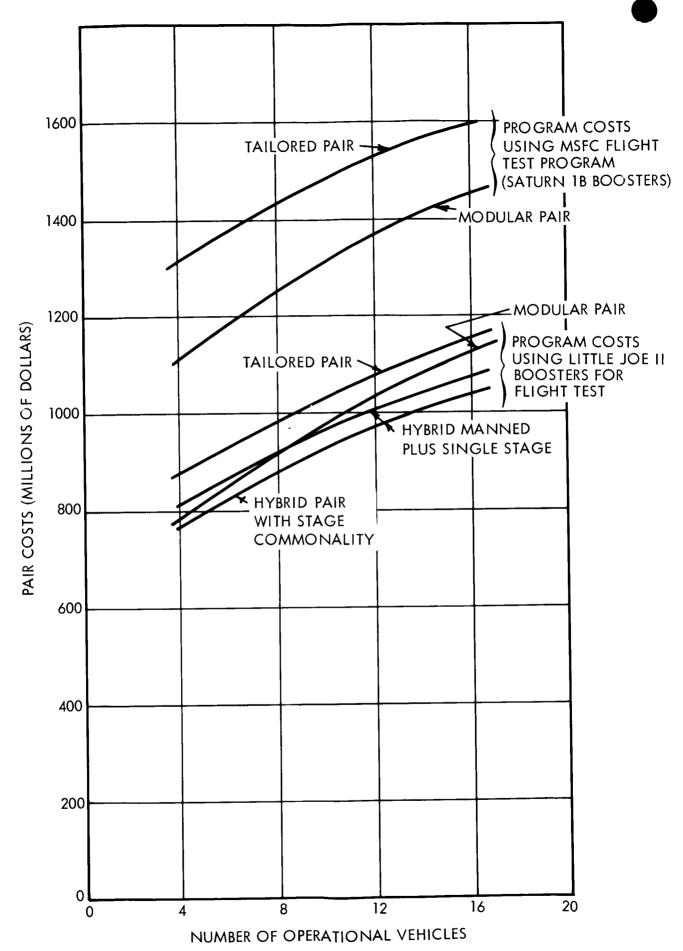


Figure 5-3. Pair Cost Summaries Including Experience Effects

Comparison of these program costs indicates the large increase in costs due to this flight test factor alone (of the order of 50 percent in the case of the tailored configurations). Another fact of importance shown by this comparison is the increase in the cost difference between the two pairs. The fact that the modular pair requires appreciably fewer test flights is emphasized when the expensive boosters are utilized.

Also repeated in this figure are the pair consisting of the hybrid manned and the single-stage logistics as well as the hybrid pair when commonality is assumed. These curves are repeated here to indicate the magnitude of the cost differences they provide in comparison with the other major cost factors discussed above.